Developments in Locomotive Practice

C. J. BOWEN COOKE

A LIST OF WORKS

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SOME RECENT DEVELOPMENTS IN LOCOMOTIVE PRACTICE

BY

C. J. BOWEN COOKE

ASSISTANT RUNNING SUPERINTENDENT, LOCOMOTIVE DEPARTMENT
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PREFACE

In the early part of last year the Commandant of the School of Military Engineering at Chatham invited Mr. F. W. Webb, the Chief Mechanical Engineer of the London and North-Western Railway Company, to give two lectures to the Royal Engineers' Institute upon "Recent developments in Locomotive Practice."

The arduous duties of Mr. Webb's responsible office leave him but little time for outside work, and he kindly suggested my name as a substitute. I must frankly acknowledge I felt considerable diffidence in occupying a position originally offered to a man of his unique reputation; but his ready assistance, supplemented by the information other Locomotive Engineers were good enough to give me, and the reception with which I met at the hands of the Royal Engineer Officers and Engineering Pupils have to a certain extent dispelled my misgivings.

The Members of the Royal Engineers' Institute, having done me the honour of preserving these letters by printing them among their professional papers, I venture with their kind permission to offer them to a wider public, in the hope that they may contain information interesting to others who watch the growth of Locomotive development in this country.

The subject is set forth under the various headings and sub-sections which were given me as a synopsis on which to work, and which I have endeavoured to follow carefully in accordance with the wishes of the authorities.

*

While asking my readers to deal leniently with faults of omission, or commission, which I fear may be found in this attempt to confine so wide a subject within the space of two lectures of one hour's duration each, I must at the same time apologise if here and there the phraseology seems more suited for its original purpose, namely, a *viva voce* exposition with illustrations on a screen, than for the letter-press of a book.

ERRATA

Page 14, line 19, *read*, 7′–0″ four wheels coupled.
,, 15, ,, 3 from bottom, *for* 4,000 feet per minute, *read*, 4,400.
,, 16, ,, 1, *read*, Horse Power found thus:—

$$\frac{4,400 \times 5620}{33,000} = 750 \text{ H.P.}$$

,, 26, ,, 14, *for* Bessemer Steel, *read*, Mild Steel.
Plate VIIA, *The date of the run shown on plate VIIa, should be* June 8th, 1899.
,, XII, *This plate is upside down.*

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SOME RECENT DEVELOPMENTS IN LOCOMOTIVE PRACTICE

ALTHOUGH in the course of the two papers that I hope to have the honour of reading on the subject of Modern Locomotive Practice I must of necessity confine myself chiefly to the details of the construction of the locomotive engine of to-day, as laid down in the synopsis that has been given to me as a framework on which to build, still I shall venture to introduce two additional phases of the subject, which I cannot but hope may prove of interest. One of these, a short historical sketch of the earlier development of the locomotive, I shall use as a preface to my first paper; the other, as a conclusion to the second, will be a brief discourse upon the management of locomotives after they are turned out of the shops and put to work on the line, as, perhaps, some of my hearers may eventually have more to do with the use and practical management of locomotives than with their actual construction.

EARLY HISTORY.

Time will not admit of my going into any lengthy details, however interesting they may be, of the early history of the locomotive, and I can only draw your attention to a few of the principal examples of the earliest types.

The first steam land carriage (*Fig.* 1) or self-moving locomotive of which there is any authentic record was made by a Frenchman named Nicholas Joseph Cugnot, in the year **1771**.

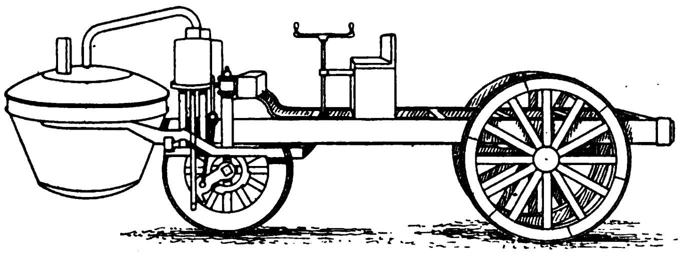


Fig. 1.

The boiler was a sort of kettle-shaped vessel made of copper, through which the cylinder passed, and the piston acted on a ratchet wheel on the driving axle, each stroke giving $\frac{1}{4}$ revolution to the driving-wheel. The maximum speed attained is said to have been $2\frac{1}{2}$ miles per hour. The French government took some interest in this notion of a steam land carriage, thinking it might prove useful for military purposes, and voted a sum of money towards its construction; but on one of its trials the machine overturned in the streets of Paris, after which it was locked up in the arsenal, thus bringing its brief career to an abrupt termination.

James Watt, thirteen years later, brought out an idea for a locomotive. Like Cugnot's, it ran on three wheels and had a single vertical cylinder; the piston was connected to a beam pivoted at the opposite end, and attached by a connecting rod to the driving-wheel.

Fig. 2 shows Trevithick's engine built in the year **1803**; *this was the first locomotive ever made use of for a practical purpose*, and we may be proud of the fact that it was produced by an Englishman.

William Hedley constructed an engine which worked at the Wylam Colliery in **1811**. This is the celebrated "Puffing Billy," now in the South Kensington Museum.

George Stephenson's first attempt at a locomotive was made in the year **1815**. He still employed vertical cylinders; but the connecting rods were coupled direct on to the cranks, fixed on the wheels, and at right angles to each other, a system that has been invariably adopted since this engine was built at the beginning of the last century, the reason being that with cranks at right angles the engine is never on a dead centre. The wheels were coupled by an endless chain, and here we have history repeating itself, as this is

the present system of coupling the driving gear to the wheels of the modern motor car.

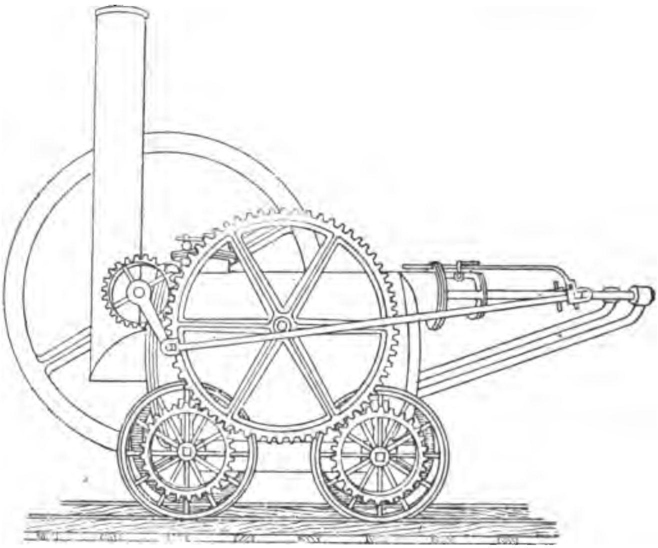


Fig. 2.

A steam coach (*Fig.* 3), built by Mr. David Gordon about this date, shows the ideas people had in those days. It was fitted with propellers, supposed to act in the same way as a horse's hind legs, being alternately pushed into the ground and drawn back again.

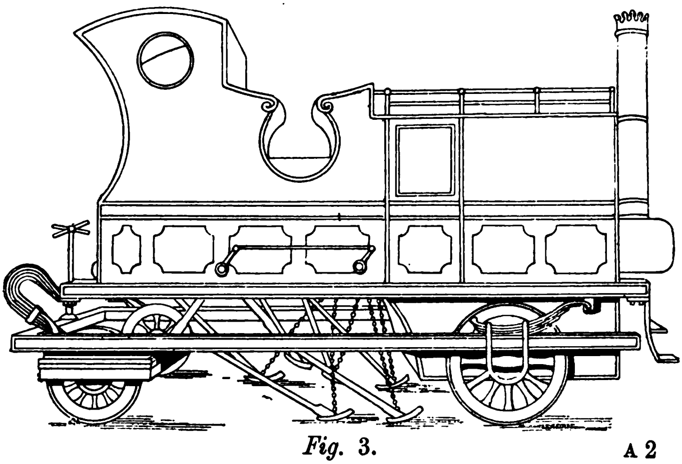


Fig. 3.

In **1825** the Stockton and Darlington Railway was opened, and *Fig.* 4 is a small sketch of the engine that drew the first train on the first public railway in the world, opened for traffic 76 years ago.

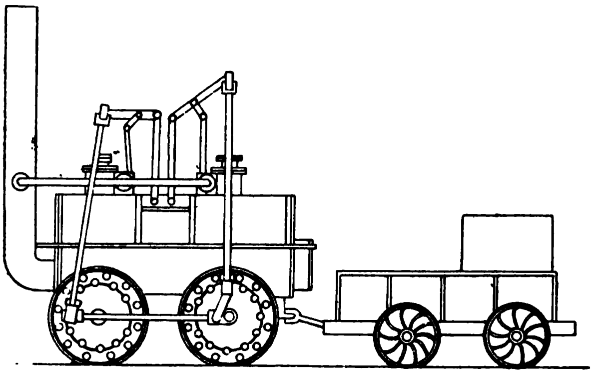


Fig. 4.

We may here pause to draw a comparison. This, the first passenger engine that ever ran in the world's history, weighed in working order 6½ tons, the boiler pressure was 25 lbs. per square inch, the cost £600, and the speed of the train 15 miles per hour. Some of our modern engines weigh upwards of 80 tons, have a boiler pressure of 200 lbs. per square inch, cost over £3,000, and run at any speed up to 70 miles an hour.

The Royal George, built by Hackworth in **1827**, had the exhaust steam turned into the chimney, another important feature in the development of the locomotive. Here for the first time we have the "blast pipe," which has been described as the "life breath" of the high-pressure engine.

Even up to the date of the Rainhill contest in **1829** the practicability of locomotives as a commercial success was by no means generally recognized, and the directors of the Liverpool and Manchester Railway, which was completed in that year, had not decided on the power that was to be used for drawing their trains; but the famous historical contest, in which the "Novelty" (a tank engine carrying its own supply of fuel and feed water), the "Sanspareil," and the "Rocket" took part, settled once and for all the much debated question, by the victory won by Stephenson's "Rocket" on that notable day. The cylinders in an inclined direction, the firebox, the tubular boiler, and indeed all the leading principles of the modern locomotive engine and boiler, show them-

selves for the first time in the "Rocket," although still in a very crude form as regards detail of design (*Fig.* 5).

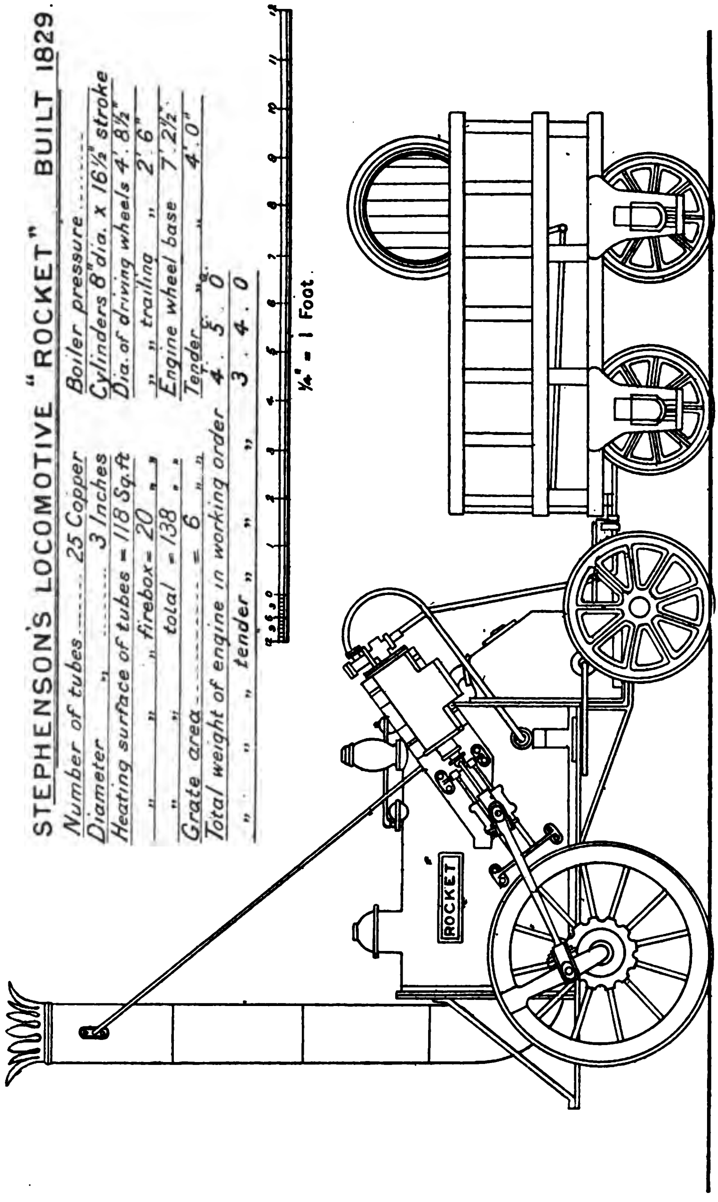


Fig. 5.

After the Liverpool and Manchester Railway was opened, locomotives and locomotive builders sprang up all over the country. An interesting engine was built in **1833** by "Carmichael," of Dundee, which had outside vertical cylinders connected on each side by cross-heads and side links to bell crank levers, transmitting the power to the driving wheels. This engine shows us the first example of the idea of a bogie, the trailing end being carried on a small truck with separate wheel base of its own.

Fig. 6 shows the class of engine on the Liverpool and Manchester Railway in 1834, which ran on four wheels and had 11″ × 16″ horizontal cylinders, and may be taken as the standard type of passenger engine working on the English railways for the succeeding ten years; in several respects an approach may be noticed towards a more modern form of design.

In **1847** began the great battle of the gauges, and Brunel's famous single wheel broad gauge engine (*Fig.* 7), built about that date, inaugurated a type of engine used by the Great Western Railway Company for many years, in fact until the date of the abolition of the broad gauge on May 20th, 1892.

The "Cornwall" (*Figs.* 8 and 8A), a single engine with 8-foot 6-inch driving wheels, built by Mr. F. Trevithick, was, indeed, and still is, a famous engine, running to-day on the L. & N.W. Railway, although built so long ago as 1847. Originally constructed with the boiler underneath the axle, to get the centre of gravity as low as possible, with a view to ensuring greater safety when running at a high speed; it was afterwards rebuilt and is still at work, and this time-honoured veteran at the ripe age, for a locomotive, of 55 years is still doing serviceable work.

A very powerful engine (*Fig.* 9), built by McConnell, and known as the "Bloomer" class, was put on the L. & N.W. Railway about the same time. It had larger fire-box, cylinders, and heating surface than any other contemporary engine. It ran for many years on the southern division of the L. & N.W. Railway, indeed up to the time that Mr. Webb built his 6-foot 6-inch coupled engines in 1873, which are running express trains to-day. These latter engines have really done splendid work on the line. As an example, the "Charles Dickens" (*Fig.* 10) has for 19 years worked from Manchester to London and back every day, except when stopped for repairs, and up to the end of December, 1900, had run 1,877,176 miles, thus holding the world's record in the number of miles run by any one engine. In the famous race from London

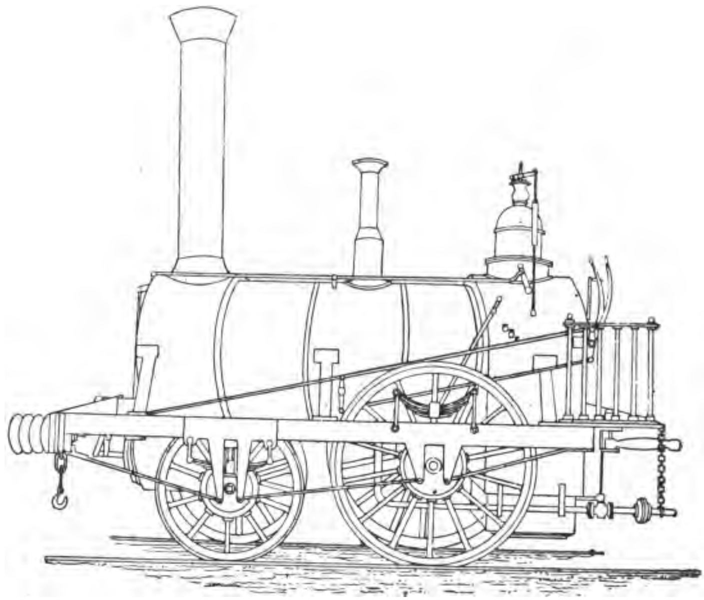


Fig. 6

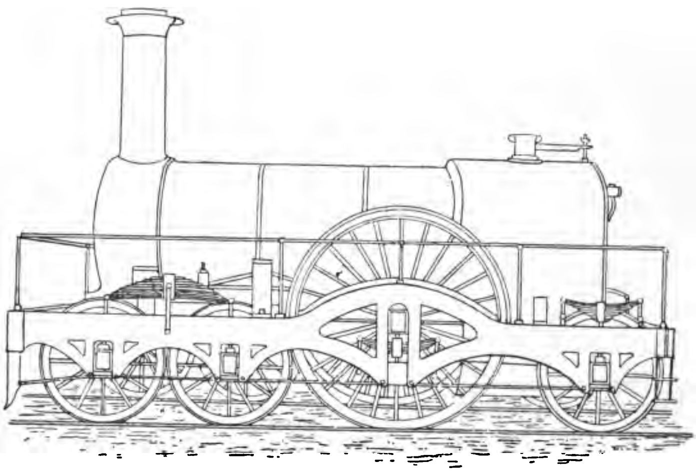


Fig. 7.

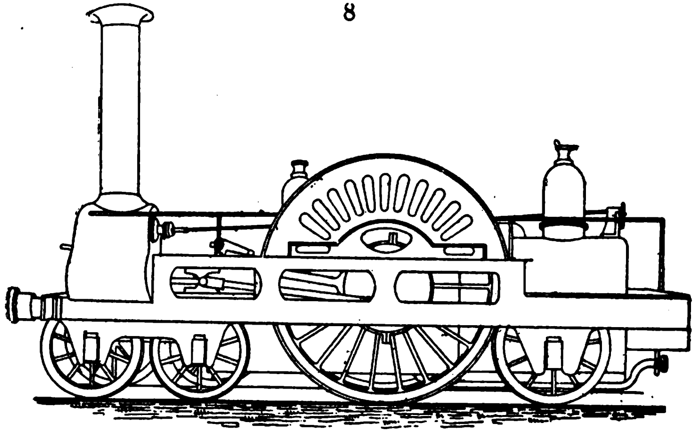


Fig. 8.

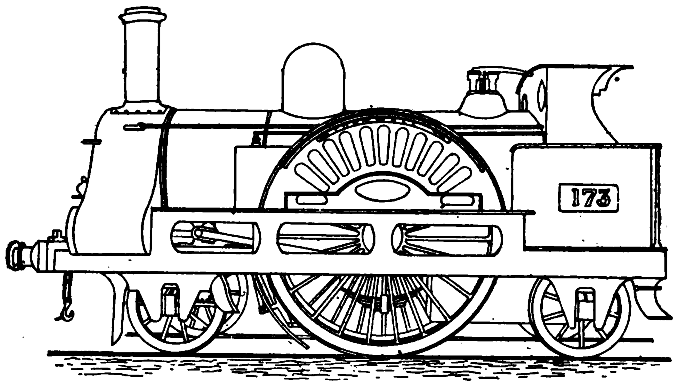


Fig. 8A.

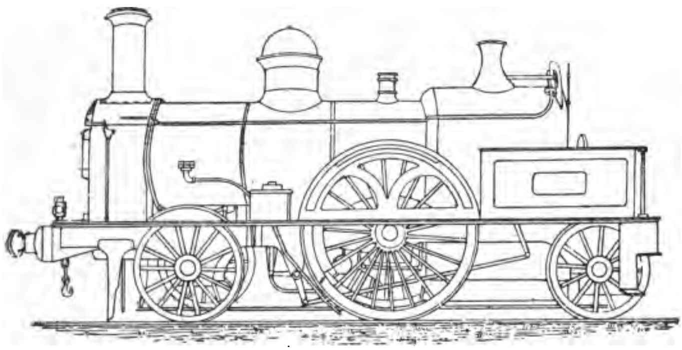


Fig. 9.

to Scotland in 1895, the Scotch express, worked by engine "Hardwicke" of the same class, ran from Crewe to Carlisle, a distance of 141 miles, at the rate of 67·2 miles per hour. When we take into consideration that this distance traverses over some of the heaviest gradients on any main line in the country, and that the notable bank at Shap Fell being on a gradient of 1 in 70 has to be ascended, the performance was indeed a remarkable one, and has never been beaten in this or any other country.

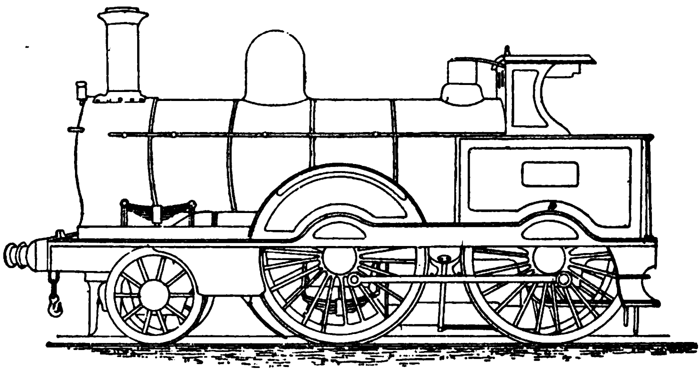


Fig. 10.

(1). The Conditions Governing the General Design.

Having led up, though very intermittently, to a more modern type of locomotive, we may now proceed to consider some of the conditions governing the general design of the locomotive of to-day.

During the latter part of the period we have briefly reviewed trains and engines were very much lighter than they are now, and the road upon which they had to run was of a totally different character to the modern permanent way. Fifty years ago rails weighed 75 lbs. to the yard; this has gradually increased, and now rails weigh about 100 lbs. to the yard.

Locomotives and trains have developed in weight, and it has now become necessary to increase the weight on the driving wheels to secure the necessary adhesion to the rails. This has frequently caused dissension between locomotive and civil engineers. While the former has been obliged to increase the size and weight of his engine to enable him to haul the increased weight of train authorized by his directors, the permanent way department has

not always been able to keep pace with this increase, and the civil engineers have been continually crying out about the tremendously increased weight on the rails.

Plate I. shows at a glance the gradual increase in the length and weight of trains on the L. & N.W. Railway since the year 1864.

(*a*). *Load on Driving Wheels.*—It is of course evident that the greater the adhesive weight the less chance of slipping, but it is now generally accepted that the maximum weight on a single pair of wheels should not exceed 20 tons. In single engines this weight can only be utilized on one pair of wheels; it therefore follows that we soon reach a limit to the weight of train capable of being hauled by single driving engines.

The maximum of 20 tons is not often reached, because of the great strain on the permanent way, and on the older railways the bridges were not originally constructed to bear anything like this weight. The weight can, of course, be more equally distributed when coupled engines are employed, and it is now the general practice to couple four wheels with passenger engines, six wheels with express goods engines, and eight wheels with engines required to run heavy loads at slow speeds. *Plate* II. shows the weight carried on the different wheels with the principal types of standard engines on the L. & N.W. Railway.

(*b*). *Resistance to Traction.*—The resistance due to traction may be divided into three parts:—

Firstly.—Resistance dependent on velocity. Due to the friction of the moving parts of the engine and vehicles, and to the displacement of the air at the given speed.

Secondly.—Resistance due to gravity. In ascending an incline the train is of course raised vertically a distance, depending upon the length and inclination of the grade.

Thirdly.—Effect of wind and curves. High winds cause a very great increase in the resistance, this being particularly the case when the direction of the wind is at right angles to the rails, causing it to act upon the whole length of the train surface, thus producing excessive friction on the flanges of the wheels. The practical engine driver, who knows little of the theory of train resistance, knows only too well the difficulties he experiences in keeping time when there is a strong side wind, and when there is a gale blowing from the east or west the number of assistant engines worked on trains out of Euston in the course of one day

RECI

GRAM

PLATE II.

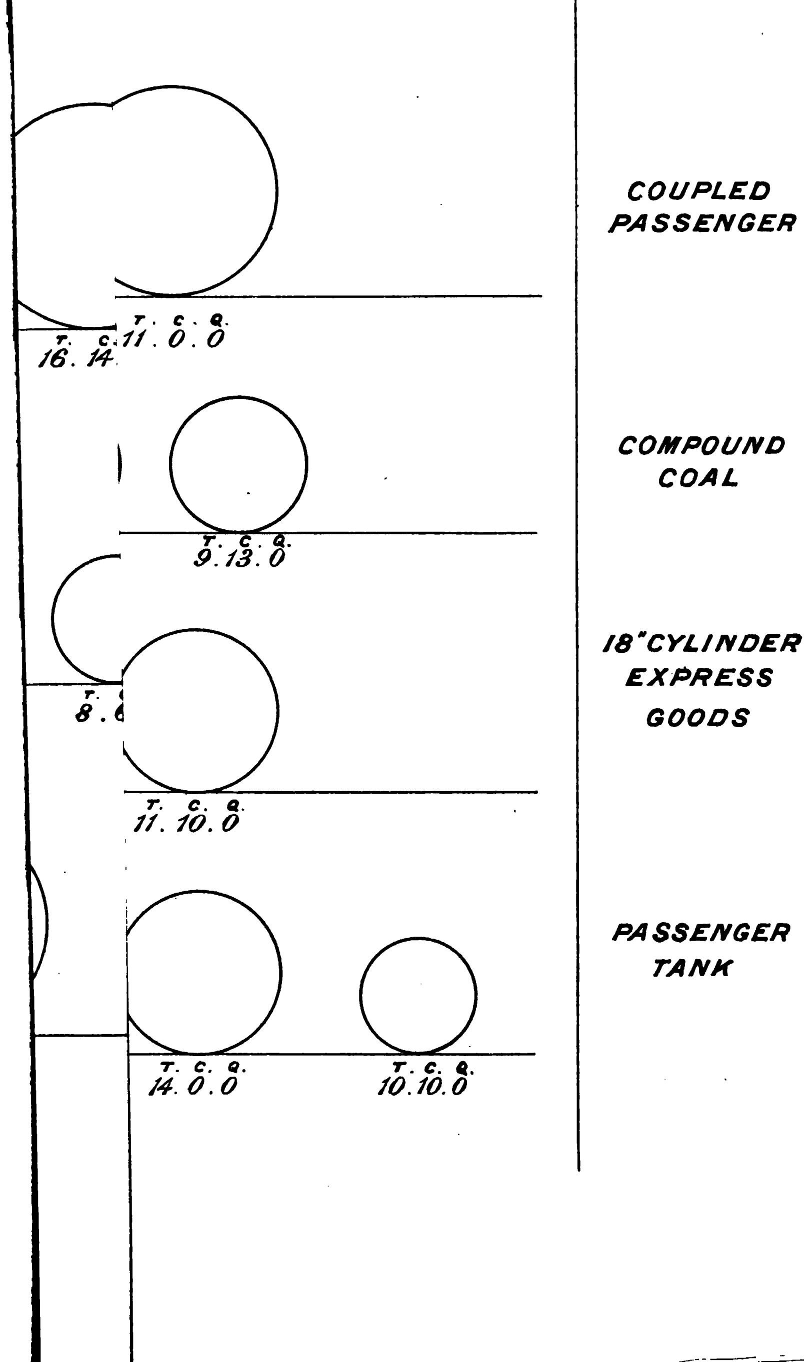
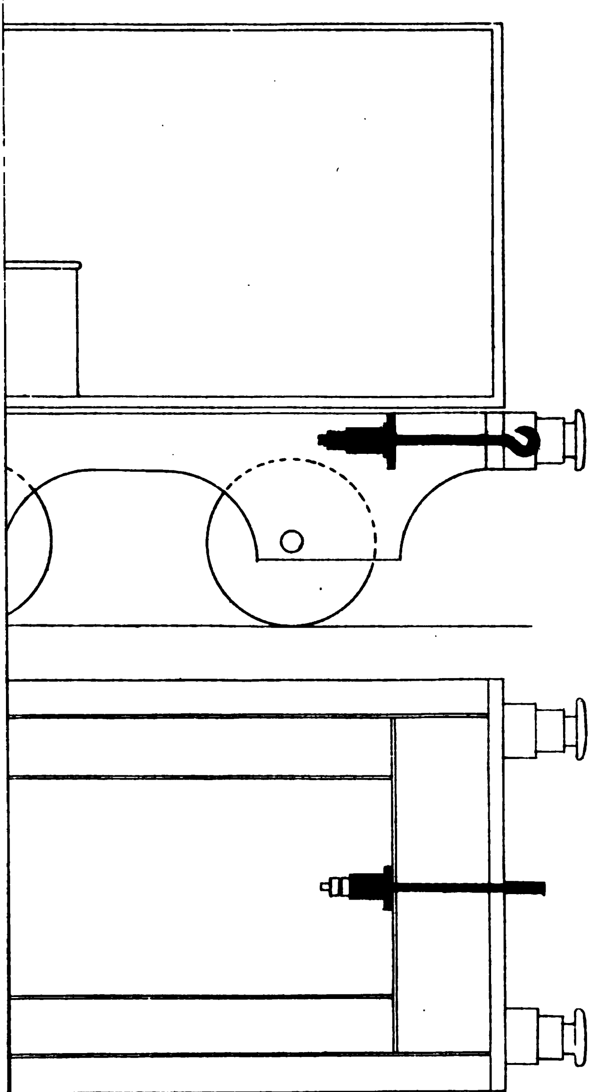


PLATE III.

IN LOCOMOTIVE PRACTICE.

WESTERN RAILWAY.

gram of Traction Gear.



Arm keyed on Drawbar. C,. *Pencil for*
ected to arm B, through lever L.
pull up to 11½ tons. E,E',. *Buffers connected*
heads loose on drawbar, and abutting on
aper roll moving across table.

is a serious item of expense. A head wind meeting the train fair and square does little harm, as the actual surface presented to the wind is only equal to the cross-section of the train. Curves also considerably increase the resistance, particularly with engines that have a long rigid wheel base. This resistance is considerably reduced by the provision of bogies, or radial axle-boxes, which will be alluded to later on.

Many elaborately theoretical calculations have been made, from which various formulæ have been deduced, to show the power required to be exerted by a locomotive to perform certain work under certain given conditions. I do not propose, however, to go into any of these theories or calculations, but I will show you in a very simple form the actual hauling power required, and the actual performance of certain standard passenger and goods engines working typical passenger and goods trains on the main line of the L. & N.W. Railway.

Mr. Webb has, at Crewe, a machine known as a "Dynamometer" car (*Plate* III.). This car is about 19 feet long and 8 feet wide, and is carried upon three pairs of wheels. It is used to register the tractive pull of the engine, to indicate the speed at which the train is running, and to locate any place or point on the road passed over. A roll of paper, K, about 1 foot wide, is fed across a table at a certain rate, say 3 inches per mile, by gear connected to the middle axle, and on this paper four pencils record lines; two of them (one fixed to record datum-line, and one free to travel with the draw-bar) are used to register the tractive pull of the engine. Both these pencils are in a line at point C when there is no pull on the bar.

When the draw-bar is in tension the cross-head H′ moves inwards and compresses the springs DD′, and when the buffers are in compression the cross-head H moves inwards and also compresses the springs, the pencil C connected to the draw-bar recording a line to the right or left of the datum-line accordingly.

The third, or speed pencil, is controlled by an electric magnet which is connected to a clock, and every half minute, as the paper passes over the table, the magnet causes the pencil to make a notch in the line, and by scaling the distance between these notches the speed can be ascertained.

The fourth, or locating pencil, is also controlled by an electric magnet which is connected to electric pushes fixed round the car, and by means of these pushes a notch can be made in the line at

any desired spot, the name of station, mile post, etc., being written opposite to it.

The scale is constructed as follows :—

The paper is fed, as stated, at 3 inches per mile, therefore when the train is running at 60 miles per hour, or a mile in one minute, one half-minute interval would measure exactly one and a-half inches between the notches ; the one and a-half inches are, therefore, divided into 60 equal parts representing miles, and form a scale by which the speed can be read off.

The speed and locating pencils are not shown on the diagram, and I only propose to deal with the question of the pull on the draw-bar, which gives the actual practical train resistance and hauling power required, and the diagram shows in simple form how the draw-bar of the train is coupled up to the dynamometer car by means of this arrangement of levers.

I will now put before you several instances of the train resistance, etc., recorded in various trips with this car.

The records shown in *Plate* IV. were made on July 16th, 1893, with a special coal train from Rugby to Willesden, a distance of 77 miles.

AB is the datum-line described by the fixed pencil. The zigzag line is the diagram drawn by the pencil free to travel with the draw-bar.

The height of the diagram above the datum-line represents the actual pull on the draw-bar. Where the pencil travels below the datum-line, the draw-bar is in compression due to the brake being on the front part of the train.

The engine working the train was an 8-wheel non-compound coal engine, with 2,000 gallons tender. The train consisted of 57 loaded coal-wagons, 3 brake-vans, and dynamometer car. The total weight of the train, including engine and tender, was 852 tons 13 cwts. 1 qr. ; excluding engine and tender, 777 tons 12 cwts. 1 qr. ; and its total length was 1,263½ feet. The steepest rising gradient on this section of the line is 1 in 326.

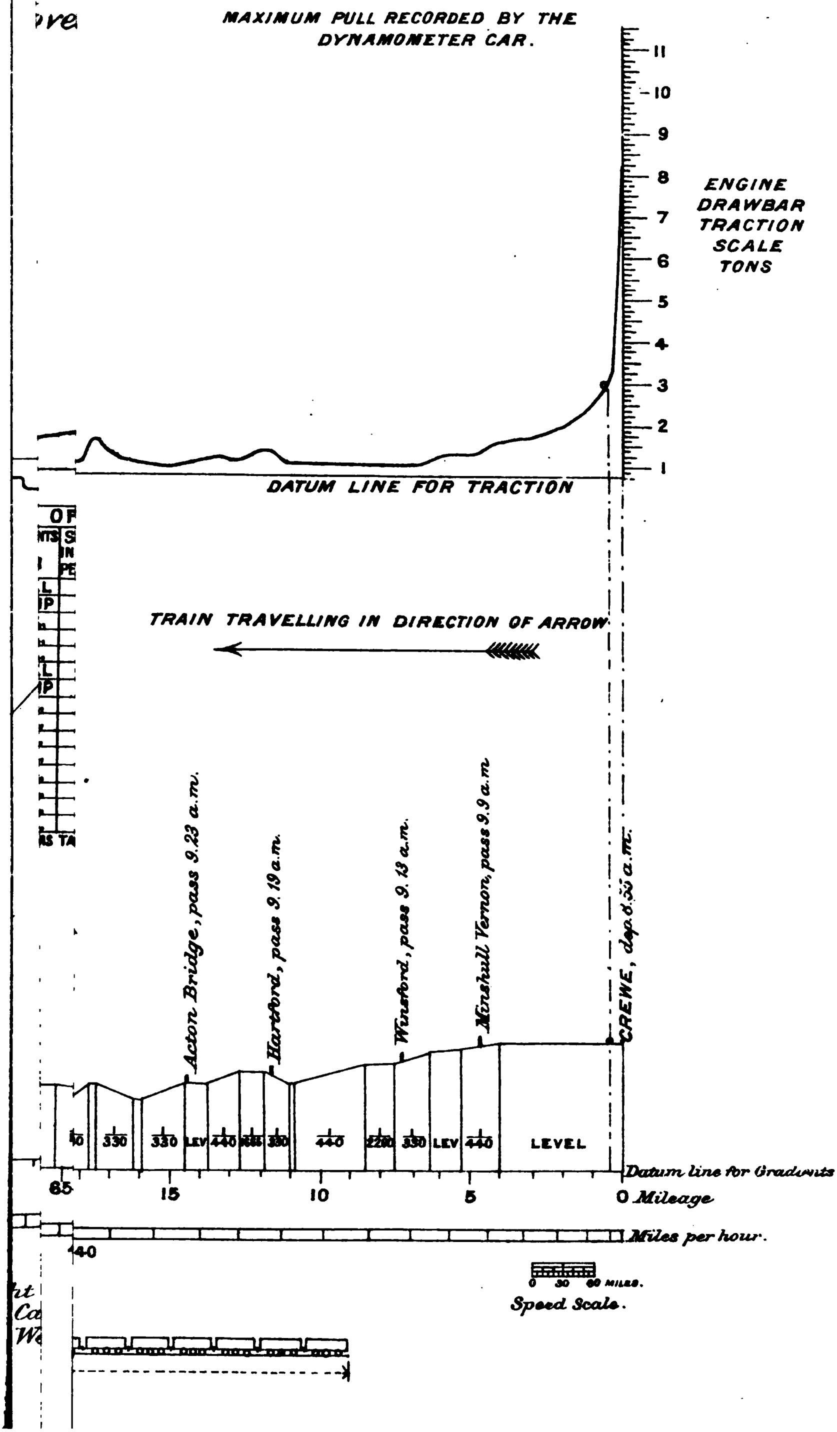
The highest speed recorded on the journey was 25 miles per hour.

As an example of the hauling power exerted, notice at X the steady pull on an up gradient of 1 in 330 at 12 miles an hour.

At this point the I.H.P. was 411, and the pull on the draw-bar $4\frac{7}{16}$ tons.

The highest I.H.P. developed was 557 on up gradient of 1 in 326 at 13 miles per hour, with a pull on draw-bar of 5 tons.

PLATE V.



MAXIMUM PULL RECORDED BY THE DYNAMOMETER CAR.
ENGINE DRAWBAR TRACTION SCALE TONS
1
2
3
4
5
6
7
8
9
10
11
DATUM LINE FOR TRACTION
TRAIN TRAVELLING IN DIRECTION OF ARROW
Acton Bridge, pass 9.23 a.m.
Hartford, pass 9.19 a.m.
Winsford, pass 9.13 a.m.
Minshull Vernon, pass 9.9 a.m
CREWE, dep. 8.55 a.m.
330
330
LEV
440
330
440
220
330
LEV
440
LEVEL
Datum line for Gradients
65
15
10
5
0 Mileage
Miles per hour.
40
0
30
60 MILES.
Speed Scale.

The pull on draw-bar at starting was $11\frac{1}{4}$ tons.

The ruling gradient on the southern section of the L. & N.W. main line is 1 in 330. It, therefore, follows that to haul a coal train weighing 777 tons at 12 miles an hour up this gradient the engine must be capable of exerting a direct and continuous pull equal to $4\frac{7}{16}$ tons.

The next diagram (*Plate* V.) was taken on November 29th, 1896, with a trip from Crewe to Carlisle, a distance of $141\frac{1}{4}$ miles, with a train consisting of 25 passenger vehicles worked by an 8-wheel compound coal engine, with 2,000 gallons tender, and the following particulars should be noted :—

The total weight of the train, including engine and tender, was 354 tons 9 cwts. 2 qrs.; excluding engine and tender, 278 tons 12 cwts. 2 qrs.

The total length of the train was 962 feet 6 inches.

Steepest rising gradient, 1 in 75.

Highest speed on journey, 48 miles per hour.

Speed up gradient of 1 in 75, 19 miles per hour.

I.H.P. on up gradient of 1 in 75, 704.

Pull on draw-bar on up gradient of 1 in 75, $5\frac{1}{8}$ tons.

The highest I.H P. developed was 781 on up gradient of 1 in 120, at 27 miles per hour.

The pull on draw-bar at starting from Crewe was 8 tons, and on starting from Carnforth was $11\frac{1}{2}$ tons.

The highest pull on the draw-bar whilst running was $5\frac{1}{8}$ tons, going up Shap Bank on rising gradient of 1 in 75, at 19 miles per hour.

Plate VI. shows a trial run with a heavy goods train, also worked by an 8-wheel compound coal engine of the same class, with 2,000 gallons tender, over a very heavy piece of road between Edgeley and Heaton Lodge, a distance of $29\frac{1}{2}$ miles, on December 1st, 1896, giving a good example of the working of a heavy goods train over a hilly road. The train consisted of 47 wagons.

Total weight, including engine and tender, 445 tons 14 cwts. 3 qrs.; excluding engine and tender, 369 tons 17 cwts. 3 qrs.

Total length of train, 991 feet.

Total number of axles in train, 103.

Steepest rising gradient, 1 in 66.

Highest speed on journey, 27 miles per hour.

Speed up gradient of 1 in 125, 21 miles per hour.

I.H.P. up gradient of 1 in 125, 745·5.

Pull on draw-bar up gradient of 1 in 125, $5\frac{1}{16}$th tons.

The highest I.H.P. developed was 767·8, on up gradient of 1 in 120, at 23 miles per hour.

The pull on draw-bar at starting was $9\frac{3}{8}$ tons.

The pull on draw-bar in starting on up gradient of 1 in 66 was $11\frac{1}{2}$ tons.

The highest pull on draw-bar whilst running was $7\frac{3}{4}$ tons.

The last of these examples (*Plates* VII. and VII.A) is of a famous run from Euston to Crewe and back, in the summer of 1899, with a train weighing, including engine and tender, 420 tons, conveying the members of the Institution of Civil Engineers. This is a very good example of the actual power exerted by an express passenger engine when running a heavy train an average speed of 50 miles per hour, which may be accepted as a fair standard of ordinary express passenger train speed in this country. The performance of the engine, however, was unique, because, although the speed was not out of the way, the weight of the train was altogether exceptional.

Euston to Crewe, June 8th, 1899 :—

Length of trip, 159 miles.

7-foot 4-inch wheels, coupled compound express passenger engine, "Iron Duke," 2,000 gallons tender, dynamometer car, and 13 saloon carriages.

Total weight of train, including engine and tender, 420 tons 5 cwts.

Total weight of train, excluding engine and tender, 339 tons 5 cwts.

Total length of train, 716 feet 2 inches.

Steepest gradient, 1 in 70.

Highest speed on journey, 65 miles per hour.

Speed up gradient of 1 in 330, 47 miles per hour.

Pull on draw-bar of 1 in 330, $2\frac{1}{2}$ tons.

The pull on draw-bar at starting was $4\frac{3}{4}$ tons.

The highest pull on draw-bar whilst running was $5\frac{1}{4}$ tons, going up Camden Bank, on gradient of 1 in 70, at a speed of 16 miles per hour.

The mean pull on draw-bar throughout the journey was 1·485 tons.

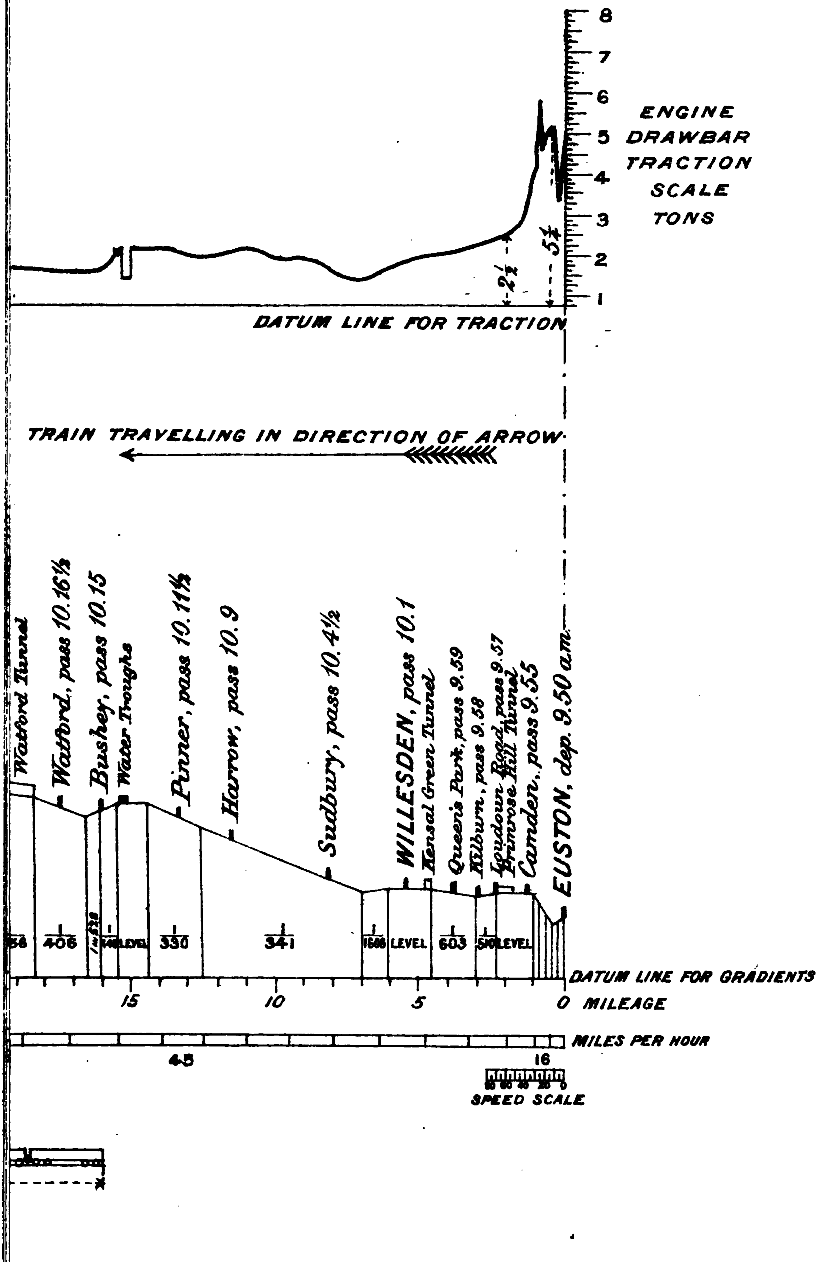
The trip of 159 miles was run in 3 hours 15 minutes without a stop.

Crewe to Euston, June 8th, 1899 :—

Length of trip, 159 miles.

The same engine worked the train, and the weights and lengths were similar to those on the down journey.

PLATE VII.



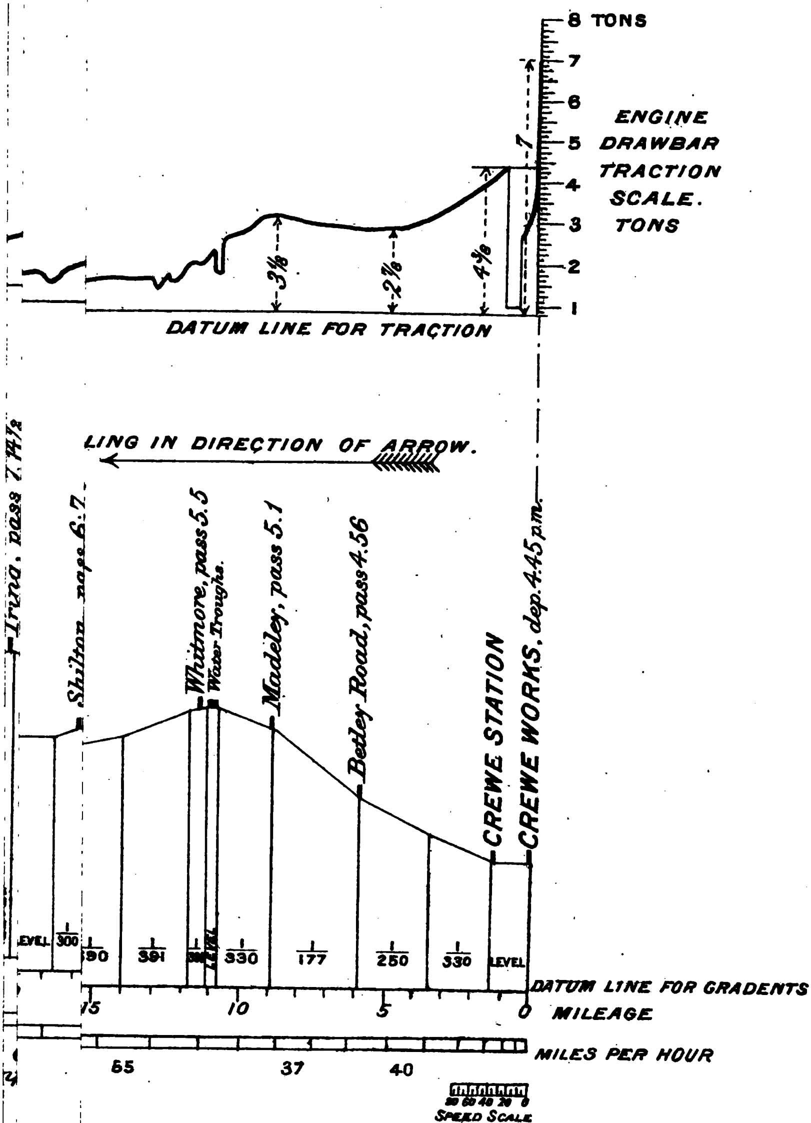
ENGINE DRAWBAR TRACTION SCALE TONS
8
7
6
5
4
3
2
1
$2\frac{1}{4}$
$5\frac{1}{4}$
DATUM LINE FOR TRACTION
TRAIN TRAVELLING IN DIRECTION OF ARROW
Watford Tunnel
Watford, pass 10.16½
Bushey, pass 10.15
Water Troughs
Pinner, pass 10.11½
Harrow, pass 10.9
Sudbury, pass 10.4½
WILLESDEN, pass 10.1
Kensal Green Tunnel
Queen's Park, pass 9.59
Kilburn, pass 9.58
Loudoun Road, pass 9.57
Primrose Hill Tunnel
Camden, pass 9.55
EUSTON, dep. 9.50 a.m.
406
330
341
1686
LEVEL
603
510
DATUM LINE FOR GRADIENTS
15
10
5
0 MILEAGE
MILES PER HOUR
45
16
SPEED SCALE

IVE

ILW

fro

PLATE VII^A



Steepest gradient, 1 in 177.

Highest speed on journey, 65 miles per hour.

Speed up gradient of 1 in 330, 48 miles per hour.

Pull on draw-bar of 1 in 330, $2\frac{3}{16}$th tons.

The pull on the draw-bar at starting was 7 tons.

The highest pull on draw-bar whilst running was $3\frac{1}{8}$ tons on up gradient of 1 in 177, at a speed of 37 miles per hour.

The train ran from Crewe to Willesden, 154 miles, without a stop.

In the two trips, up and down, the engine covered a distance of 318 miles.

The mean pull on draw-bar throughout the journey was 1·56 tons.

This trip, therefore, practically demonstrates that a heavy express passenger train running at 50 miles an hour develops a mean train resistance of 1·56 tons. Now, the well-known formula by D. K. Clarke for train resistance is

$$R = 8 + \frac{v^2}{171}$$

per ton for total resistance, including engine and tender.

Applying this to the L. & N.W. train, whose run we have been dealing with, we have

$$R = 8 + \frac{50^2}{171} = 22{\cdot}6 \text{ lbs. per ton.}$$

The whole train, including engine and tender, weighed $420\frac{1}{4}$ tons, which multiplied by 22·6 gives as a mean resistance 9,500 lbs., or 4 tons 4 cwts. 3 qrs. 8 lbs. It therefore appears that the formula gives far too high a result.

Commenting on this, the *Engineer* of the 14th July, 1899, remarks as follows:—

"Even if we omitted the constant 8, the result would be far too high. We believe that the resistance of the train was about $1\frac{3}{4}$ tons, or 4,000 lbs., and taking weight of train at 340 tons, we have resistance thus of 11·76 lbs. per ton, and taking resistance of engine and tender, including friction of machinery, at 20 lbs. per ton, we have 1,620 lbs. more, making 5,620 lbs."

Taking average velocity of 50 miles per hour, or 4,000 feet per minute, the locomotive exerted 750 H.P.

Weight per H.P. of the locomotive was 160 lbs.

H.P. found thus:—

$$\frac{4{,}400^{*} \times 6{,}520^{\dagger}}{33{,}000} = 750 \text{ H.P.}$$

(2). The Framing.

The style of frame usually employed in this country consists of two single rolled plates of iron or steel about 1 inch in thickness. Each plate is exactly the same in every respect, and extends along the whole length of the engine at each side. They must be perfectly level and straight throughout, and these plates, together with the cylinders, cross-stays, buffer-plates, etc., which are bolted to them, form the foundation upon which the engine is erected.

Engines in this country are generally built on the single frame system, that is to say, one single frame down each side of the engine, as shown in *Fig.* 11, which is the frame of Mr. Webb's 4-cylinder compound. The elevation of the frame-plate is shown, looking at it from the inside. Although a single-framed engine, the framework is strengthened by a mid-feather, with a central axle-box to give increased bearing to the driving axle.

The frames are stayed together by means of—

(1). The buffer-plate.

(2). The spectacle or motion-plate.

(3). The transverse stay immediately in front of the fire-box.

(4). The trailing horn-blocks, which are connected to each other by a trough in which the axle works, extending between the frames.

(5). The frames are further made rigid by the cast-iron foot-plate bolted between them at the trailing end.

To illustrate at a glance how an engine is erected upon the groundwork formed by the two frame-plates, photographs were shown taken at various stages of its construction, beginning with the two bare frame-plates laid on trestles in the erecting shop at Crewe ready for the fitters to commence work.

The Midland and Great Western Railways have engines built with double frames. A diagram of double frames for Great Western single engines is shown in *Fig.* 12. IF is the inside and OF the outside frame; both of them extend along the whole length of the

* Feet passed over per min. lbs.

† 4,000 lbs. resistance for train at 11·76 lbs. per ton, and 1,620 lbs. for engine and tender at 20 lbs. per ton.

engine at either side, and are stayed at intervals by the transverse stay-plate TSP. The driving wheels have each two axle-boxes, each

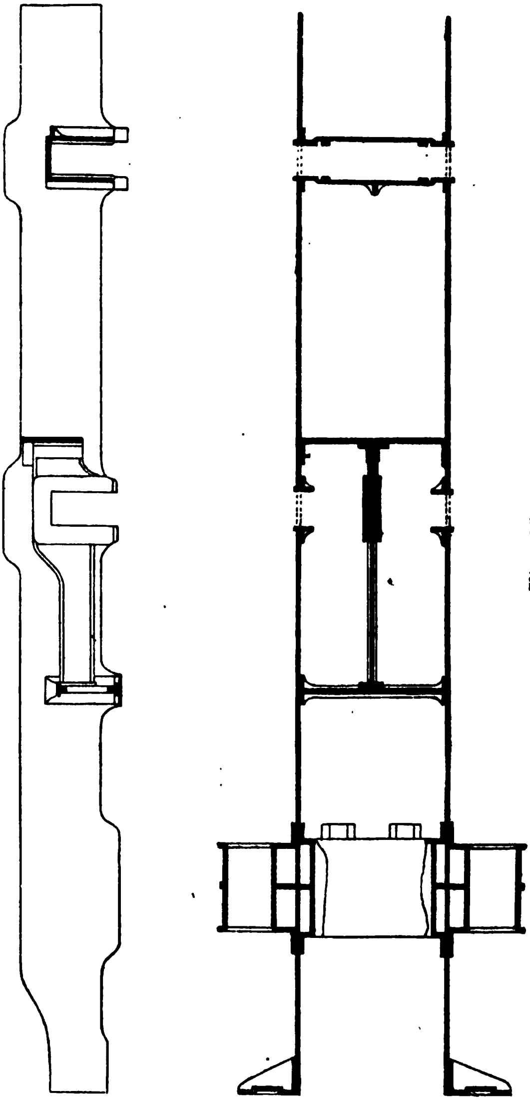


Fig. 11.

working in the horn-plates in their respective frames; the wheels are between the two frames. There are altogether six journals or

bearing surfaces upon the driving axle without counting the eccentrics, so, as may be imagined, it is a costly piece of work. The

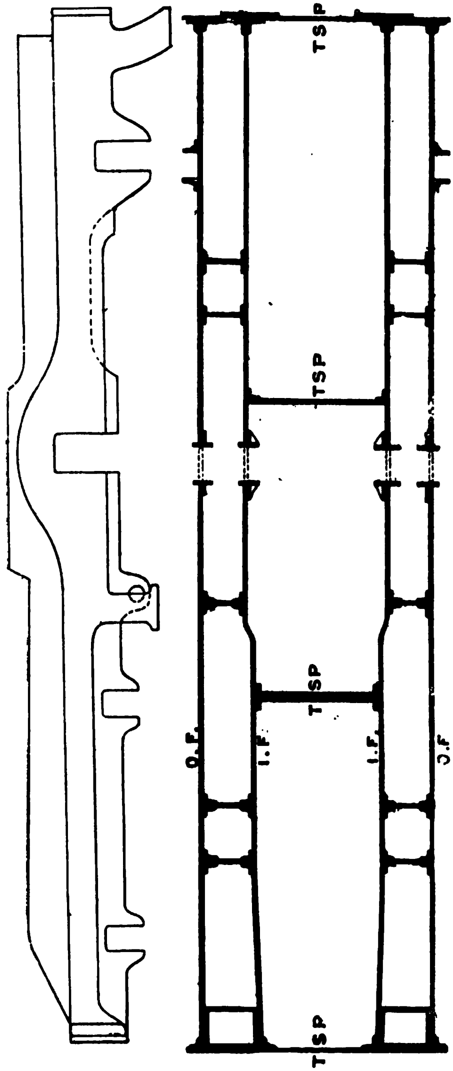


Fig. 12.

trailing wheels have axle-boxes on the outside frames only; the front end is carried on a bogie.

In America the frames are made of wrought-iron bars from 3 to 4 inches square; it is usual to make them in two parts, bolted together (*Fig.* 13). The leading part consists of flat bars, to which the cylinders are bolted; the trailing part is formed with guides or jaws for the axle-boxes to work in, and is made up of bars or braces forged together.

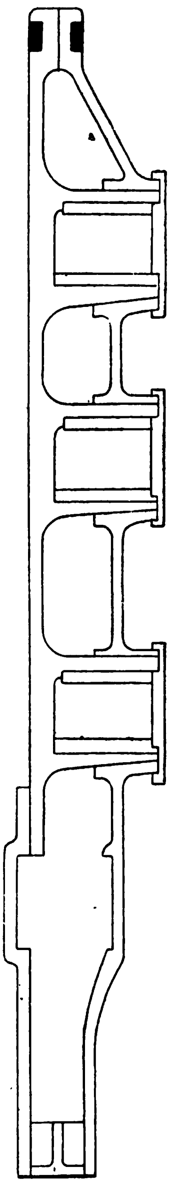


Fig. 13.

It is thought by some people that the wear and tear of the road is affected by the class of frame used, and the users of plate-frames and bar-frames respectively contend that their practice is the best for the permanent way. For my own part, I have never been able to find any data showing that one is superior to the other in this respect, but the English system is certainly, to my mind, by far the simplest, most economical, and workmanlike.

(3). Boilers.

I do not know whether it has struck any of you that in the matter of boiler construction locomotive engineers are hampered in ways which do not affect the designers of stationary engines, who, as a rule, can make their boilers of any size or dimensions they like, and fix them in any convenient spot, without having to consider the question of space. Now, with a locomotive no part may be more than 13 feet 6 inches above rail level. The width must not exceed 8 feet 6 inches or thereabouts, and the length must be in proportion to the wheel base of the engine, so as to enable it to traverse curves with safety. The weight must be correctly distributed, and, as already mentioned, must not exceed 20 tons on any one pair of wheels.

There are many other such restrictions, and when it is remembered that all the complicated details of a modern high-pressure or compound

engine, capable of exerting something like 1,000 horse-power, together with a powerful boiler for maintaining steam at an uniform pressure, and driving that machinery, have to be compressed into such a limited space, and that they have to be specially constructed to stand the wear and tear of travelling over a metal road at upwards of 60 miles an hour, it will be recognized that the design, material, and workmanship of a locomotive engine must all be of the most perfect possible of their kind.

Generally speaking, the boiler of a locomotive may be said to consist of four principal parts :

(1). The barrel, that is, the cylindrical part extending from the fire-box to the smoke-box.

(2). The fire-box shell, or casing adjoining the barrel at one end, and rectangular in shape except at the top, where it is usually a continuation of the upper half of the barrel. The bottom part extends below the barrel, and is joined to the lower half of the barrel by the shoulder-plate.

(3). The fire-box, a square chamber inside the fire-box shell, with four walls and a roof, having an open space at the bottom for the fire-grate.

(4). The tubes, a number of small cylindrical flues extending through the barrel, for conveying the gases generated by the fire to the smoke-box and chimney.

Fig. 14 is an outline section through a locomotive boiler, and shows the position of the fire-box and tubes.

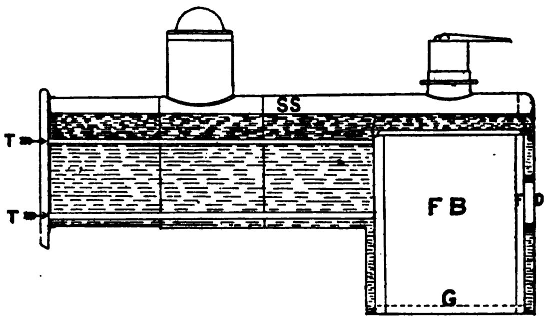


Fig. 14.

FB is the fire-box, TT the tubes, of which only two are shown, so that they can be more clearly defined. The space between them is in reality filled with tubes, the number being usually about 200.

The grate is at G, the fire-door at FD. The shaded part shows the water space, the steam space being above the water at SS.

The inside surface of the tubes and the fire-box plates comes directly into contact with the flames of the fire, and is called the heating surface. It is absolutely necessary that these tubes and the plates should (as shown in the diagram) be always surrounded by water when there is a fire in the fire-box. The space between the outside of the tubes is called the water space.

(*a*). *Material.*—The outer plates, viz., those forming the barrel and fire-box shell, are now almost universally made of mild steel. Mr. Webb was one of the first engineers in this country to successfully introduce Bessemer steel for boiler-plates, and as long ago as 1886 he had made 2,752 locomotive boilers of this material. At that date most engineers continued to make their boilers of Yorkshire iron, and some companies still retain this, to my mind, now somewhat antiquated custom.

The tubes are usually made of brass, although copper, steel, and iron all have their advocates, as being suitable for the purpose. Of course, the two latter have the recommendation of being much cheaper than brass or copper, and having the same co-efficient of expansion, and on some railways they have been successfully used. However, it is generally conceded by the majority of locomotive engineers that in the long run brass or copper tubes prove the most economical and satisfactory.

The usual thickness of the boiler-plates and tubes is as follows, varying slightly under certain conditions:—

Steel plates, barrel, and fire-box shell, $\frac{9}{16}$ inch.

Yorkshire iron, barrel, and fire-box shell, $\frac{9}{16}$ inch.

Steel plates, barrel, and fire-box shell, $\frac{18}{32}$ inch when pressure is less than 140 lbs. per square inch.

The external diameter of the tubes varies from $1\frac{1}{2}$ inches to $1\frac{7}{8}$ inches.

(*b*). *Size.*—With regard to the question of the size of locomotive boilers, this naturally depends very much on the work the engine has to perform. The great point to be aimed at is to provide sufficient heating surface to enable steam to be generated with sufficient rapidity to keep the boiler well up to its work, that is to say, not to let it "run out of breath," which is what happens when the cylinders are using the steam quicker than the boiler can supply it. Latterly, in many cases, the weight of trains has increased out of all proportion to the work the engines were originally built to perform.

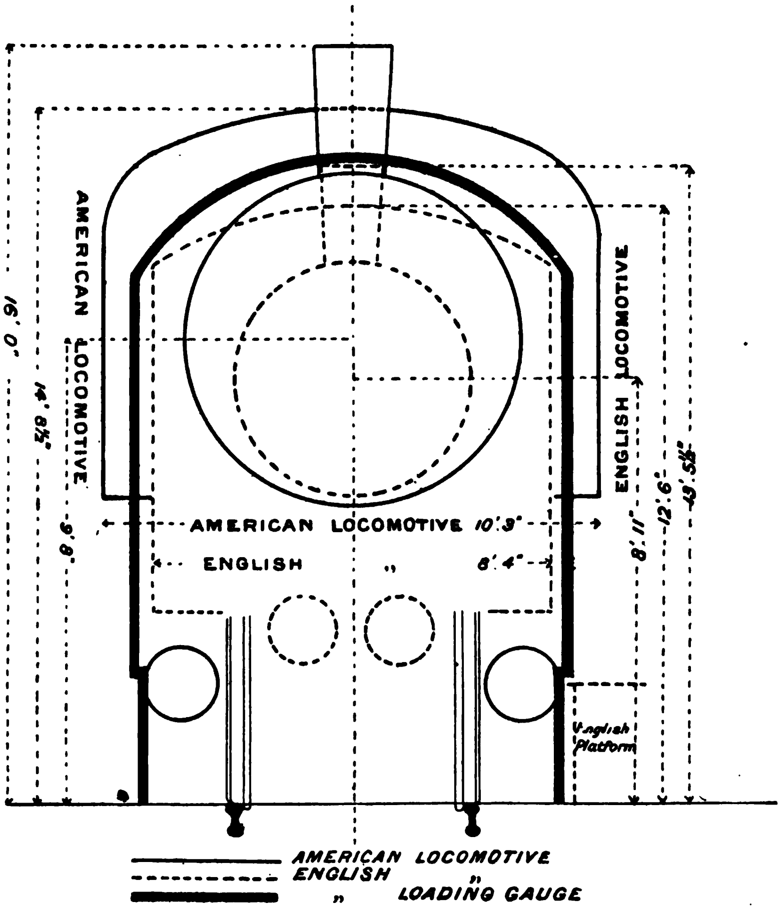

AMERICAN LOCOMOTIVE
ENGLISH LOCOMOTIVE
16' 0"
14' 8½"
8' 6"
AMERICAN LOCOMOTIVE 10' 3"
ENGLISH " 8' 4"
8' 11"
12' 6"
13' 5½"
English Platform
AMERICAN LOCOMOTIVE
ENGLISH "
" LOADING GAUGE

Fig. 15.

In trying to keep time with such trains, drivers are apt to "thrash" their engines, that is to say, they work the engine nearly in full gear instead of "cutting off" at 20 or 30 per cent. of the stroke, as originally intended, thus using a great deal more steam than the boiler can generate.

In order to gain the absolutely necessary increased power under modern conditions, engineers have been expanding the cylinder diameters, increasing the boiler pressure, and enlarging the boilers to attain increased heating surface, grate area, and steam space. The ordinary simple engine of to-day has cylinders varying from 18 to 20 inches in diameter, and probably a boiler pressure of 200 lbs. to the square inch. But the English engineer, whilst he can enlarge his cylinders and increase his boiler pressure, cannot follow the lead of his American cousin in the matter of boiler construction, because, whereas the loading gauge in this country is restricted to the dimensions I have already given, in America these restrictions practically do not exist. So long as the construction of an engine admits of safe running it practically does not matter how far it bulges out in any direction.

The diagram (*Fig.* 15) shows this very plainly. The black lines represent the external diameter in width and height of the modern American engine, while the dotted lines show the external dimensions of the latest Lancashire and Yorkshire passenger engine, which has attained the extreme limit possible with the English loading gauge, which gauge is shown by the thick black line. This, without comment, will give you some idea of the different conditions under which English and American engineers have to work to attain the same standard of boiler efficiency.

The following table gives the standard proportion of the heating surface of locomotive boilers on the principal English railways. The smallest boiler of any modern-built engine is that of the Midland Railway single-wheeled engine, while the largest is that of the Lancashire and Yorkshire Railway.

Again, to emphasize the points of comparison between English and American practice, I show the same figures with regard to some typical American engines.

English.

Railway.	Diameter of Cylinders.	Fire Grate Area.	Heating Surface.		
			Fire-box.	Tubes.	Total.
	Inches.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.
L. & S.W., 6′ 7″, Coupled...	18 × 26	24	148	Fire Tubes 1187 Water Tubes 165 1352	1500
Midland, 7′ 9″, Single ...	19½ × 26	24·5	147	1070	1217
Metropolitan, 5′ 6″, Leading Tank.	17 × 26	16·7	95·6	1050	1145
L.B. & S.C., 6′ 9″, 4-Wheel, Coupled.	18 × 26	—	110·35	1349·94	1460·39
Great Central, 5′ 1″, Goods, Coupled.	18 × 26	18·85	99	1179	1278
Great Central, 7′, Passenger	18½ × 26	20	109	1209	1318
Great Western, 6′ 8″, Coupled.	18 × 26	23·15	124·41	1395·62	1520·03
L. & Y., 7′ 3″, Coupled ...	19 × 26	26·05	175·8	1877	2052·8
Midland, 5′, American Goods, 6-Wheel, Coupled.	18 × 24	16·5	120	1241·3	1361·3
G.N., re-built, 8′, Single ...	18 × 28	23·3	114	1096	1210
L. & N.W., Jubilee Type ...	2 H.P. 15 × 24 2 L.P. 19½ × 24	20·5	159·1	1241·3	1400·4
North Eastern, Compound...	1 H.P. 19 × 24 2 L.P. 20 × 24	23·0	—	—	1328

American.

	Diameter of Wheels.	Diameter of Cylinders.	Stroke Cylinder.	Heating Surface.	Grate Area.	Steam Pressure.
		Inches.	Inches.	Sq. ft.	Sq. ft.	Lbs.
Class P, 1896, 4-Wheel, Coupled.	6′ 8″	18½	26	1900	33	185
Class P, Chicago & N.W. Railway.	6′ 8″	19½	26	2507	—	—
Mogul Type, 6-Wheel, Coupled.	6′ 8″	20	28	2917	34	210
Atlantic Type	7′ 0″	20½	26	2320	69	185

Mr. Aspinall's boiler has such proportions that the extreme width and height limit possible on an English railway is reached. It has a heating surface of 2,052 square feet, with a grate area of 26·05 square feet. The fire-box is of the "Belpaire" type, about which I shall speak presently.

The outside diameter of the barrel of the boiler is 4 feet 10 inches, and the length 17 feet 1⅝ inches; the centre of the boiler is 8 feet 11 inches above rail level. It contains 239 steel tubes 15 feet long by 2 inches outside diameter, and the working pressure is 175 lbs. per square inch.

(*c*). *Working Pressure.*—Mr. Aspinall by no means reaches the approved limit of steam pressure according to modern ideas.

Ten years ago 175 lbs. was considered a very high pressure to carry, but now 200 lbs. per square inch is not infrequently used in this country, while in America the "Mogul" type of boilers carry a pressure of 210 lbs. per square inch, and the new engines on the Chemin-de-fer du Nord in France have a pressure of 212 lbs. per square inch. It may now be generally accepted that the working pressure on English railways varies from 160 lbs. to 200 lbs. per square inch.

When boilers of different classes of engines performing work of unequal importance are interchangeable, it is sometimes the practice, as the boiler gets older, to reduce the pressure it carries, and put it on the locomotive performing the less important class of work.

It is difficult to give any correct data with regard to the life of a boiler, this depending so much on the conditions under which it

works. It is never correct to give it in years, but it should always be in miles. For instance, on the L. & N.W. Railway all important express engines run on an average at least 300 miles a day, whereas on many other lines about 150 miles is considered a good day's work. It is therefore manifest that, given the same conditions, a North Western boiler would only last half the time. I have known cases of Crewe-built boilers running from 500,000 to 700,000 miles before being condemned.

(4). Fire-Box.—Relative Merits of Copper and Steel.

(*a*). The fire-box plates are almost invariably made of copper on account of its high conductivity for heat, and its ability to stand alternate expansion and contraction from heat and cold without cracking and molecular change.

Since Bessemer steel has attained its present state of perfection, making it available for boiler-plates, some enterprising engineers have tried to use it also for fire-box plates in locomotives. A measure of success has attended these experiments, but the general result has been to demonstrate that the very best copper that can be procured is far superior to any other metal for the purpose.

The temperature in a locomotive fire-box varies to a great extent, the variations at times being very sudden, and covering a great range. At one moment an engine is dragging a heavy train at high speed, with a fire urged by a fierce blast, and fed by a strong draught from below. Under such conditions the furnace is developing the maximum heat it is possible of producing. The next moment steam is shut off and the blast ceases, the damper is shut and there is no draught from below, all possible means being used to check the heat, and prevent the generation of steam not then required for working the engine. Steel fire-box plates will not stand such sudden strains, and although they are cheaper than copper in the first instance, the enduring powers of the latter under the conditions described, and its superiority as a conductor of heat, have proved it again and again to be the most economical in the long run.

With a boiler constructed in the ordinary way the top of the fire-box shell is cylindrical, whereas the top of the fire-box itself is flat, and it is most important that the roof of the fire-box should be efficiently stayed. There is great pressure on this plate. For instance, with a L. & N.W. 7-foot compound engine pressed at

200 lbs. per square inch, the total pressure on the top of the fire-box amounts to no less than 257 tons.

The usual way of staying the top of a fire-box is by strong wrought-iron girders placed longitudinally across the top of the box, to which they are attached by $\frac{7}{8}$-inch bolts screwed in steam tight through the top of the fire-box plate. These girders are slung to angle irons attached to the inside of the fire-box shell, thus making the whole thoroughly rigid when subjected to downward pressure. The view (*Figs.* 16 and 17) shows how this is done. The sides of the fire-box are secured to the sides of the fire-box shell by copper stays. The stays have threads on them; one end is screwed into the fire-box plate, and the other into the shell. After they are screwed into position the ends project beyond the outside of each plate, and these ends are riveted over.

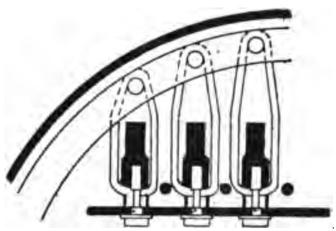


Fig. 16.

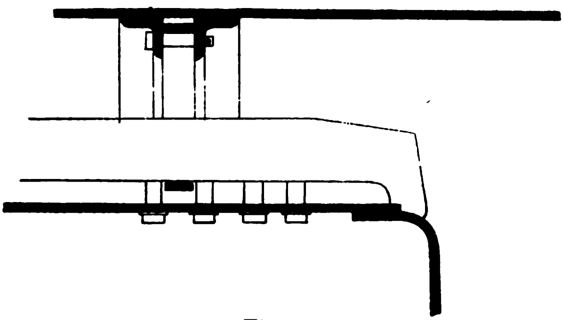


Fig. 17.

(*b*). The latest type of boiler and fire-box, known as the "Belpaire," embodies several improvements. It admits of a larger steam space above the top of the fire-box, does away with the space taken by the cumbersome roof bars, and with the many crevices and projections in which dirt is apt to accumulate.

With the "Belpaire" boiler the top of the fire-box shell is flat, and the top of the fire-box is stayed direct to the fire-box shell, as shown in *Figs.* 18 and 19; the flat sides of the fire-box shell above

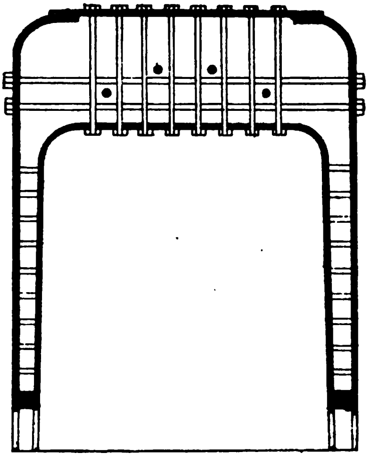


Fig. 18.

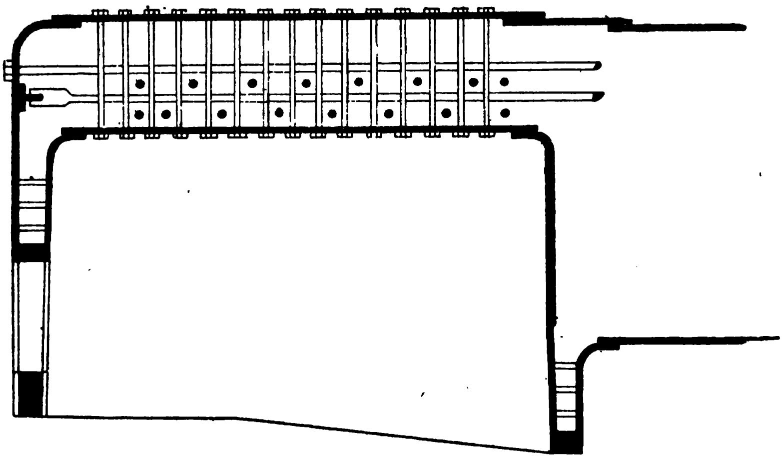


Fig. 19.

the top of the box are stayed by long transverse rods. This class of fire-box and boiler have been introduced successfully on many railways, but I believe in some cases trouble has been experienced in consequence of leaking and broken stays, due to the difficulty

PLATE VIII

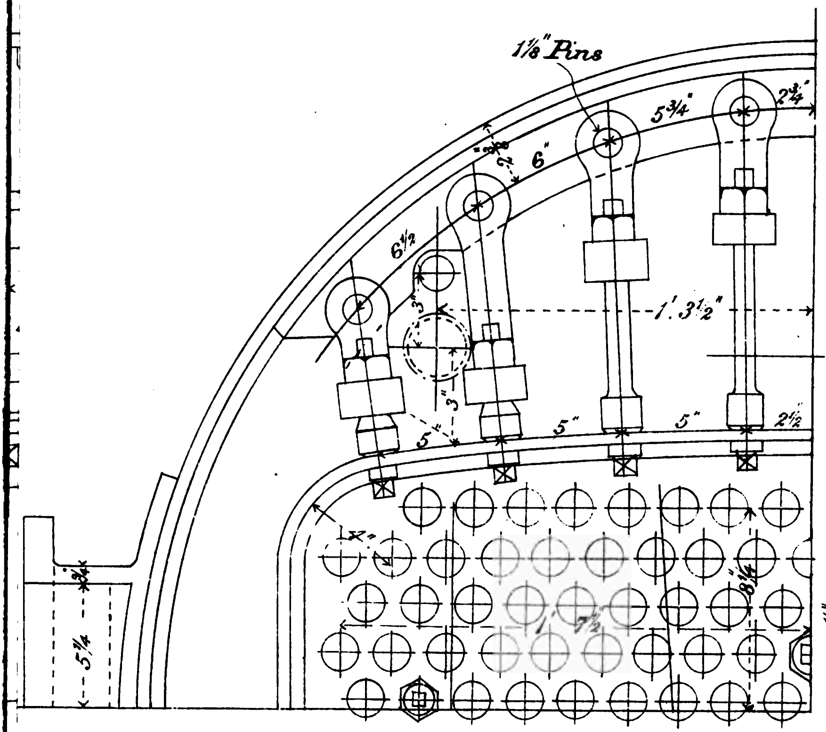
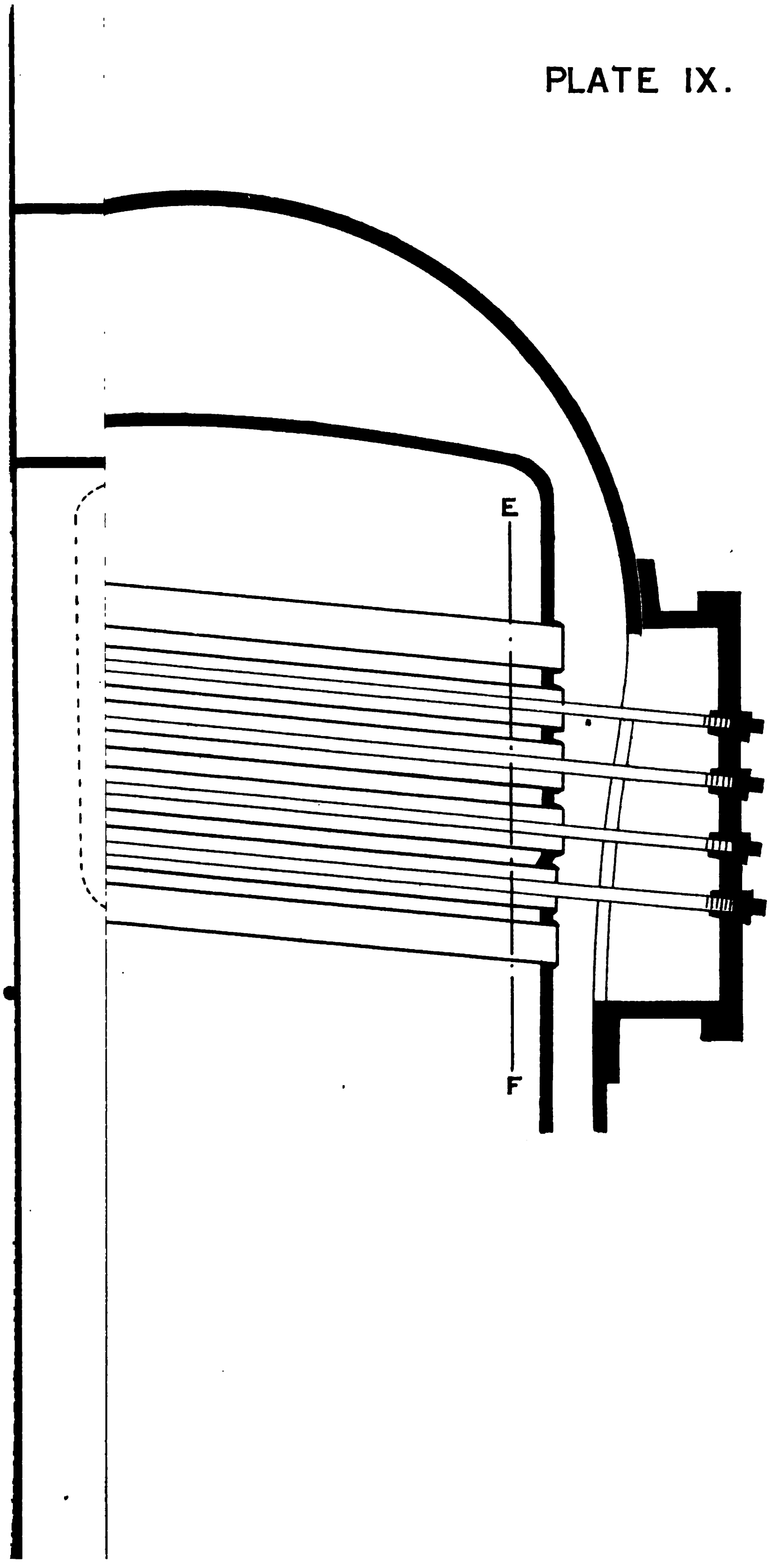


PLATE IX.



in efficiently staying such a large area of flat plates subjected to high pressures and heavy strains.

Without resorting to the "Belpaire" fire-box, Mr. Drummond, the Locomotive Superintendent of the South Western Railway, obtains the same freedom of circulation above the fire-box roof by the arrangement of roof-stays, shown on the sketch (*Plate* VIII.) In this system the roof-stay bolts are fixed to the hangers, which are attached by bolts to a row of double angle iron, riveted inside the fire-box shell. While these bolts efficiently bear the weight of the whole downward pressure on the top of the box, they are free to work upwards in the bolt holes, and a lateral movement is also given, thus freely allowing for any difference in expansion and contraction between the copper fire-box plates and steel boiler-plates.

(*c*). *Drummond Cross Tubes.*—It is a generally accepted fact that by far the most effective portion of the heating service of a locomotive lies in the fire-box; in fact, the surfaces of the tubes nearest the smoke-box are very little good indeed as regards their heating surface capabilities. Indeed, Mr. Drummond goes so far as to assert that their utility in this respect is of little value except for the first foot from the fire-box tube-plate.

Here again we see the difficulties of constructing a large boiler for an English locomotive. It is useless to lengthen the barrel, because long fire tubes do not cause additional effective heating surface, and the length of the fire-box is practically determined by the strength of the fireman's arms. It is not a bit of good having a fire-box so long that the fireman cannot throw the coal right into the front far corners. With a view of increasing the fire-box heating surface, Mr. Drummond has introduced into the fire-box a number of almost horizontal water tubes, which are arranged transversely in the top of the fire-box (*Plate* IX.). The total heating surface of the boiler is 1,500 square feet, of which the fire-box furnishes 313 square feet, which is more than twice the usual heating surface for which the fire-box is responsible.

These water tubes are made of steel, solid drawn, 2½-inch bore by ⅛ inch thick. There are altogether 61 of them, and they give a total heating surface of 165 square feet. The manner in which they are fixed in the fire-box is clearly shown in the plate. The slope is given to promote circulation, and it is equal to the diameter of the tubes. Each tube has a stay passing through the centre of it in the manner shown. This outer cover can be taken off for the purpose of inspection.

It is found in actual practice that very little scale or dirt collects in these cross tubes, and Mr. Drummond is satisfied that they add very greatly to the boiler efficiency of the South Western engines.

(5). Grates.

The area of the grate surface in its relation to the heating surface of the boiler is a very important factor in the construction of the locomotive, but it is a subject upon which there is considerable diversity of opinion and practice.

Again referring to the table with reference to the heating surface, you will see how very different is the practice with regard to the fire-grate area on the different railways, varying from 20 to 26 square feet, with the same size of cylinder, and practically the same heating surface.

You will notice that the Midland American goods engines have a very small grate area, viz., only 16·5 square feet, and I believe that these engines have been found to be very expensive in the consumption of coal. A fairly large grate area and a well-managed fire conduce in a great measure to economical working. With a small grate area the fire must be continually urged and replenished in order to maintain steam. You will also notice the extent to which it has been possible to increase the grate area on the American locomotive.

The American engine with the largest grate area is the "Atlantic" type, running on the much advertised "fastest express trains in the world," on the Philadelphia and Reading Railway, from Camden to Atlantic City. These trains are timed to run 55½ miles in 50 minutes, being a booked speed from the start to stop of 66·6 miles per hour, and according to the official records time is not only being kept, but actually made up with very respectable loads.

(*a*). *For burning Ordinary Fuel.*—*Fig.* 20 shows the arrangement of the bars in an ordinary coal burning fire-box. The fire-bars FB rest upon the carriers CC; two of these carriers are made of cast iron and extend from side to side of the fire-box, one at the front underneath the tube-plate, and the other at the back under the fire-hole.

The central carrier is made of wrought iron, and extends across the centre of the box.

The front and back carriers are held in position by the bolts B which pass through the foundation ring, and are riveted over at R. These bolts project some 4 inches into the fire-box, and upon

them are fixed washers W to keep the carriers away from the side of the box.

The carriers are screwed up by the nuts N against the washers, and are thus kept firmly in position.

The central carrier is supported by brackets which are riveted to the fire-box plate through the foundation ring.

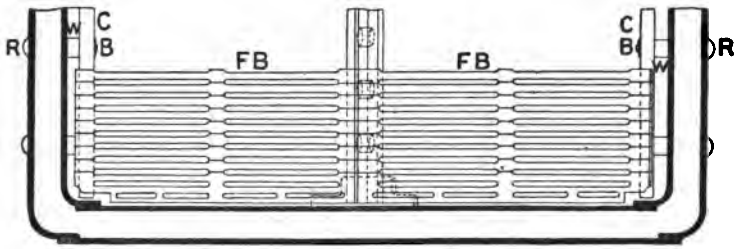


Fig. 20.

To prevent the gases from being drawn away by the blast before they are properly consumed, a brick arch is fixed in the position shown in *Fig.* 21 ; this deflects the gases as they arise from the furnace, and throws them back where the blast is greatest, thus causing their full combustion.

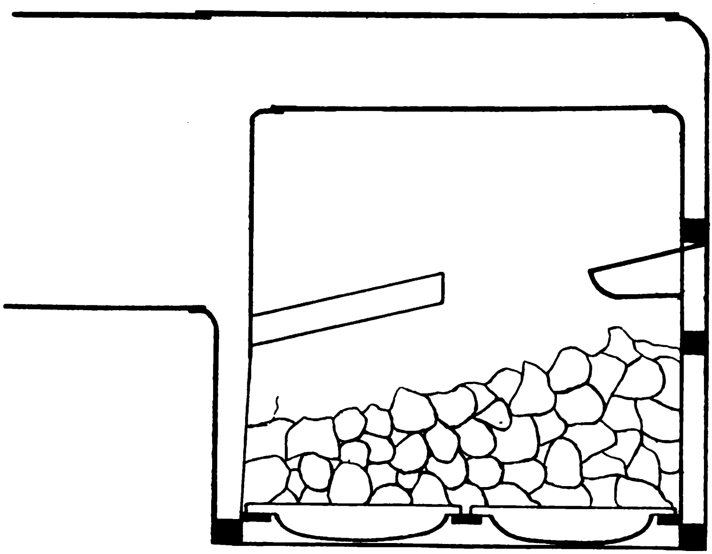


Fig. 21.

The baffle-plate over the fire-hole door acts in a similar way and throws down the air admitted to the fire-box when the door is opened; this helps combustion and prevents cold air from getting to the tube-plate and tubes. There is no baffle-plate fixed in the L. & N.W. fire-boxes; by an arrangement of Mr. Webb's the fire-hole door is made to open inwards, and thus serve the double purpose of baffle-plate and door.

(*b*). *For burning Anthracite Coal.*—Practically the grate employed for burning anthracite coal, or Welsh steam coal, is the same as when ordinary sharp coal is used, but the manipulation of the fire is different with the two kinds of coal.

With ordinary "sharp" or quick-burning coal a thin fire must be kept on the bars; whereas with anthracite coal a thick fire, as shown in *Fig.* 21, must be made up and well burnt through before the engine attempts to work a train, and the fire should be kept at this consistency while running, to ensure the most economical results.

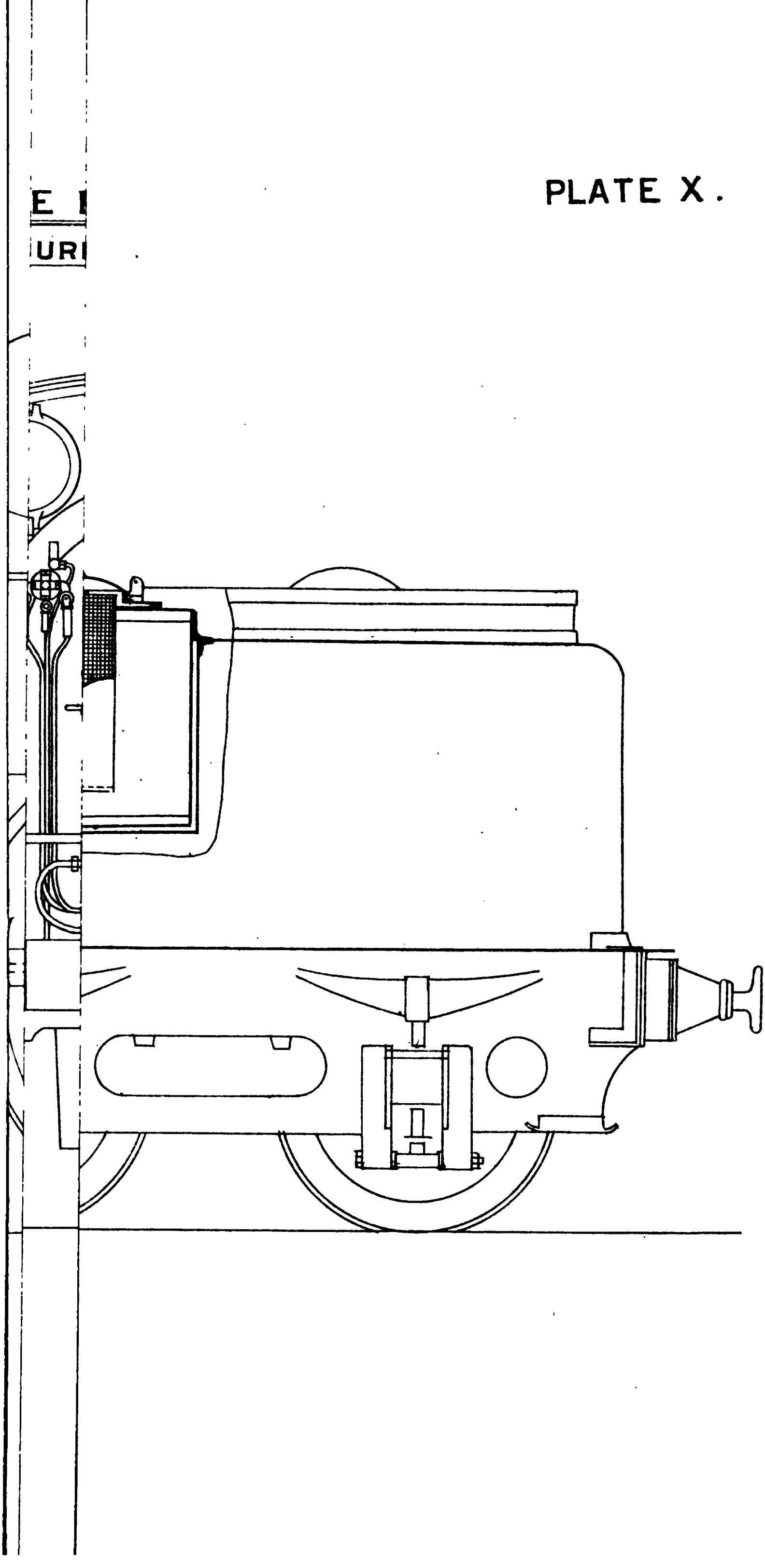
It is very important in constructing the fire-grate of a locomotive that the bars should be easily taken out, as they are apt to fuse from excessive heat when burning coal that forms clinker. It is also necessary to pull out several bars to drop the fire at the end of the day's work.

(*c*). *For burning Liquid Fuel.*—Mr. Holden, the Locomotive Superintendent of the Great Eastern Railway, has introduced a very important feature in the development of locomotive practice in this country by inaugurating a system of burning liquid fuel, and *Plate* X. is a drawing giving details of the system. Practically, the fire-box is of the same construction as an ordinary coal burning box, but has a brick wall next to the tube-plate under the brick arch. The liquid fuel, carried in a 500-gallon tank on the tender, is led by pipes to two injectors or burners placed in orifices in the fire-box plates exactly 12 inches above the bars, this height having been decided upon after a number of experiments.

Upon the ordinary fire-bars which have been already described a layer of broken fire brick is spread, the depth of the layer being 9 inches at the back immediately under the burners, 4 inches in the centre, and 6 inches in front.

The engine is lighted up in the usual way by a small fire of coal on the centre of the bars, and the injectors are not used as a rule until it is time to start with the train. During the whole time while running, the injector steam cocks are kept open, and the

PLATE X.



admission of oil is regulated by the oil cocks according to the working of the engine.

When standing, only a small jet of oil can be used, because in order to consume any quantity the action of the blast is necessary.

When working heavily, the oil is admitted in larger quantities; when notched up, the admission is reduced.

When running, no coal is used unless it is found the engine is not steaming well, in which case a thin fire is kept over the bricks.

A small fire is also put on preparatory to coming to a stand for any length of time, because if the burners are shut off, the bricks soon cool down and become black, and when the spray of liquid fuel is put on again it fails to ignite.

The supply of air to the injector is from the front of the engine through a bell-shaped orifice at the bottom of the smoke-box, whence it passes through a number of small pipes running round the smoke-box, and eventually through a larger pipe to the injector.

This raises the temperature of the air, which at the time of entering the injector is about 400 degrees Fah., the oil 200, and the steam 250.

The injectors or sprays are said to use about 2 or 3 per cent. of the steam generated, according to the class of oil they are using.

Mr. Holden is an engineer who keeps well ahead of the work expected of the engines running on the Great Eastern Railway; his latest liquid fuel burning engines have 7-foot coupled wheels, and 19″ × 26″ cylinders. The "Claud Hamilton," an engine of this class, represents a very fine specimen of English design and high-class workmanship. It was exhibited at the Paris Exhibition, where it was greatly admired.

(6). The Value of Steam Domes for Obtaining a Supply of Dry Steam for the Cylinders.

The use of the dome is to afford additional steam space. The diagramatic illustration of the boiler (*Fig.* 14) shows how very small is the actual space available for steam alone. The dome is therefore provided to enable the steam for the regulator to be taken from as high a point as possible above the level of the water.

On the drawing (*Fig.* 22) the position of the regulator and the steam-pipe conveying the steam from the dome to the cylinders is shown.

The object of taking steam from as high a point as possible is to avoid priming, a term used to describe the state of affairs when water enters the steam chest and cylinders.

It is absolutely necessary that the steam should be conveyed to the cylinders as dry as possible. Water in the cylinder is a source of danger, and an engine priming badly has been known to actually blow the cylinder cover off; besides which, water mixed with steam detracts from the elastic properties of the latter, and causes it to be more sluggish in its entrance to and exit from the cylinders.

For many years the Great Northern Railway engines were not fitted with steam domes, and to check the passage of water, the steam was taken from a long perforated pipe fixed inside the barrel of the boiler, as near the top as possible. Mr. Ivatt, however, the present Locomotive Superintendent of the Great Northern Railway, is now fitting domes to all the new engines, and to the old ones when they go into the works to be re-boilered.

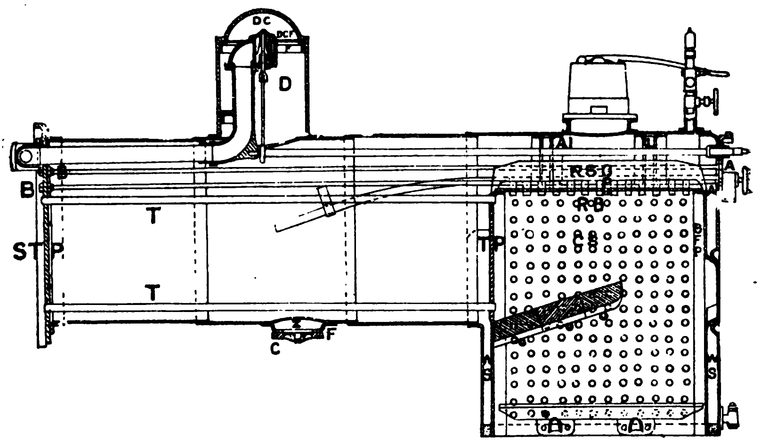


Fig. 22.

(7). Cylinders.

When the cylinders are placed side by side between the main frames, the engine is known as an "inside cylinder engine." This position necessitates the employment of cranks upon the driving axles, to communicate the force of the steam pressure to the driving wheels.

Fig. 23 illustrates the details of a pair of inside cylinders cast in one piece and bolted to the main frames at the points B. The main casting forms part of the back cover, to which the small cover BC is permanently attached. The front cover FC must be of a larger diameter, to enable the piston to be taken out for the purposes of examination, etc. In this case the valves are placed above the cylinders, a system which admits of the employment of much larger cylinders than when the valve chest is between them.

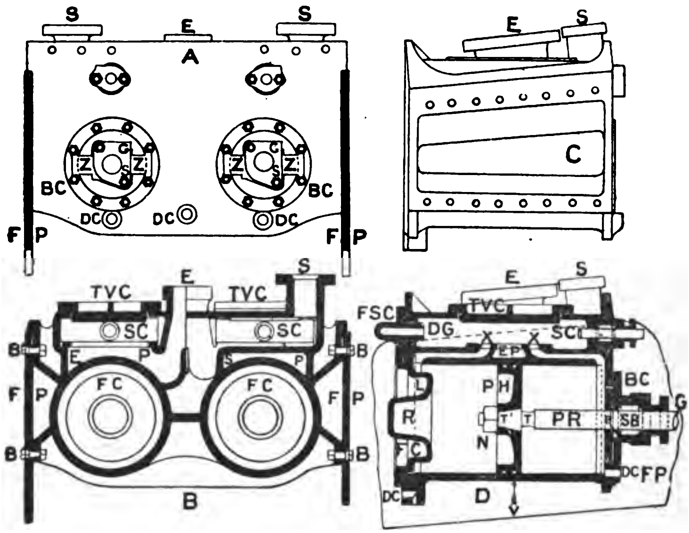


Fig. 23.

Fig. 24 shows the position of the valves when they are placed in the latter position, and in this case the two cylinders are cast separately, and afterwards bolted together. At one time they were always cast separately in this way, but owing to the joint between them being a source of trouble, it is now customary to cast the cylinders in one piece.

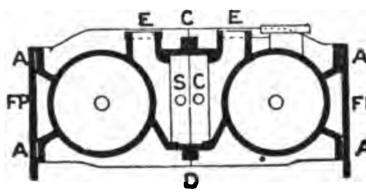


Fig. 24.

An "outside cylinder engine" has the cylinders outside the main frames on either side of the engine, and the pistons and connecting rods work on crank-pins fixed to the driving wheels. With this arrangement the axle between the driving wheels is straight, no cranks being needed.

Fig. 25 is a cross-section of the 18-inch outside cylinders of a Great Northern Railway express passenger engine built by the late Mr. Stirling. It will be seen that they are outside the frames FP at either side of the engine, each cylinder having a separate steam chest on the inner side of the frame. The frames in this case are of different design to those of an engine having inside cylinders, so as to allow space for this special form of casting. Whether the cylinders are inside or outside, they are always kept in position by being securely bolted to the main frames, as shown at A.

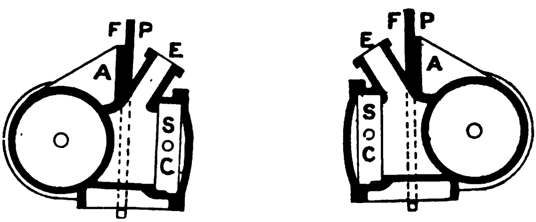


Fig. 25.

Cylinders are usually made of the best close-grained hard cast iron. The metal must be as hard as possible, subject to the condition that it is suitable for the proper fitting of its various parts.

(*a*). *Points for and against Inside Cylinders.*—Many are the arguments that have from time to time been advanced for and against the employment of inside or outside cylinders. The question is not one that concerns the cylinders alone, but it affects the whole of the general design of the engine, and each system has its own particular merit according to circumstances.

Mr. Webb disposes of the question in a very broad-minded way in his latest 4-cylinder compound engine by using both systems simultaneously. The two L.P. cylinders are between the frames, the two H.P. cylinders outside, and the arrangement has been found to give every satisfaction.

To my mind, a strong argument against outside cylinders with simple engines is the unequal distribution of the strain on the frames in consequence of the cylinders being bolted and fixed to them on

one side only. Outside cylinder engines now carry a much higher boiler pressure than in the days of Stirling and Ramsbottom, their chief upholders. This increased pressure on the piston surface puts more strain on the joint between the cylinders and the frames, and trouble is often caused by the cylinders working loose in the bolt-holes in consequence.

Another argument against outside cylinders is the cooling effect due to their exposed position, which is said to cause an excess of 16 per cent. in the condensation as compared with inside cylinders. In their favour it may be said that they are simpler and less costly in design, admitting without difficulty the use of a cylinder of large diameter; the working parts, glands, piston-rods, slide-bars, etc., are more easily accessible to the driver, and, above all, with this class of engine there is no crank axle, which is one of the most expensive parts of a locomotive, and which is occasionally liable to fracture.

The rigidity and strength given to the leading end of the engine by the solid casting of the two cylinders bolted between the frames is a point in favour of inside cylinders, and there are other advantages which have been pointed out by the comparison I have already drawn. There is, however, a difficulty in designing inside cylinders of modern dimensions with the steam chest between them, due to the fact that the area in which they must be fixed is limited to the distance of 4 feet 2 inches between the main frames, and it requires a great deal of scheming to arrange cylinders of any diameter above 18 inches with sufficiently large steam passages, and the proper thickness of metal, in this confined space.

Mr. Webb was one of the first locomotive engineers to cast the two cylinders and steam chest in one piece, and he got over this space difficulty with his 6-foot 6-inch coupled engine by placing the valves at an angle, as shown by the diagram (*Fig.* 26). This arrangement has been most successful from every point of view.

It is better, when possible, to put the steam chest in this position or directly between the cylinders, as they can be cast lighter than when there are separate steam chests above or below them, as shown in the upper one of the two diagrams.

I may here mention a few well-known types of inside and outside cylinder engines.

Coupled Engines.—The outside cylinder 7-foot coupled engine designed in the year 1881 for the South Western Railway by Mr. Adams, the then Locomotive Superintendent, was a very good specimen of a powerful engine at that time. Mr. Drummond, the

present Locomotive Superintendent, builds engines with inside cylinders, and his latest coupled engine with water tubes in the fire-box is of this type.

Single Engines.—The late Mr. Stirling's outside cylinder single-wheel engine with 8-foot driving wheels is famous for the good service it has done in past years on the Great Northern Railway; and the inside cylinder engine built by Mr. S. W. Johnson for the Midland Railway in 1889 is still doing good work.

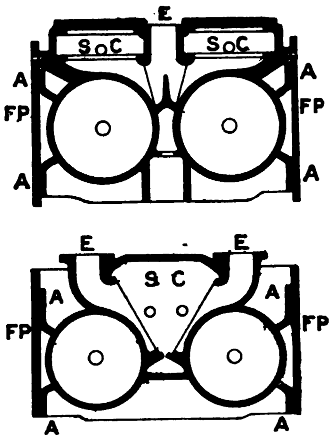


Fig. 26.

(*b*). *The Disadvantages or otherwise of Inclined Cylinders.* — With regard to the question of inclining the cylinders, or placing them horizontally. This, in a very great measure, depends upon the diameter of the wheels they have to drive, and I really do not think the inclination or otherwise of the cylinders effects any actual advantage or disadvantage as regards the working capacity of the engine. The North Western compound coal engine has the cylinders inclined to an angle of 1 in 8½, in order to give the inside L.P. slide-bars the necessary clearance above the axle of the leading wheels. This could not be obtained if the cylinder was fixed horizontally.

I have pointed out that, with the ordinary modern simple engine, the diameter of the cylinders is from 18 inches to 20 inches, and I have also pointed out the necessity of increased boiler capacity to supply cylinders of this area. This leads us to the consideration of a very important question in connection with modern locomotive development.

(*c*). *The Advantages or otherwise of Compounding.*—This is a question that has seriously exercised the minds of locomotive engineers ever since Mr. Webb first placed his engine "Experiment," No. 66, on the L. & N.W. Railway in the year 1882. Prior to that date various experiments had been made on the subject of compounding, but the matter was then for the first time seriously taken in hand, and a compound engine built and put into main line traffic on one of the leading railways in the world. While Mr. Webb has perfected and developed the system in this country, he has had few followers among contemporary engineers. On the Continent, and in other parts of the world, locomotive engineers have, however, realized the advantages to be gained by adopting his principle.

The difficulty in this country of building boilers capable of generating and maintaining sufficient steam for cylinders 18 inches to 20 inches in diameter, when working heavy loads at high speeds, is admitted by every locomotive engineer. Now with the L. & N.W. compound engines the boilers supply steam to one pair of cylinders 15 inches in diameter, the steam being exhausted into the L.P. cylinder or cylinders.

It may be argued that this is not a fair comparison, as the boiler has to supply steam not only to the high but also to the L.P. cylinders. This is no doubt partially true, but only to the extent of the difference in the cut-off between the H.P. cylinder of a compound engine and the cylinder of a simple engine, which latter, as it only uses the steam once, and in a larger cylinder has an earlier cut-off in ordinary working than in the case with a smaller H.P. cylinder with a compound engine; and it must be remembered that this H.P. cylinder is the only one receiving its direct supply of steam from the boiler.

If we can show that a compound engine, the boiler of which only has to feed a pair of 15-inch cylinders, can successfully work the heaviest and fastest trains running in the country, it ought, I think, to be a very strong argument in favour of the application of the compound principle to locomotive engines. This conclusion also seems to point to the fact that any further development required to meet the ever-increasing demands for additional power will have to be on the same lines.

At the Paris Exhibition, the world's hub for the time being, where were collected specimens of every up-to-date improvement in applied science, there were altogether 48 typical passenger and goods engines exhibited. Of these 48 only 14 were not compound engines.

Of the simple engines three were strictly British exhibits—one being a Baldwin goods engine for the Great Northern Railway Company; two were designed by Mr. McIntosh for the Belgian State Railways, and one was built by Messrs. Neilson, of Glasgow, for the Niederlandische Railway. Seven of the 14 were therefore of distinctly British origin.

Plate XI. is an illustration of the latest type of L. & N.W. Railway 4-cylinder compound engine, and this is the engine which was exhibited at the Paris Exhibition. The two H.P. cylinders are 15 inches in diameter by 24 inches stroke, and the steam is exhausted into two inside L.P. cylinders $20\frac{1}{2}'' \times 24''$ stroke.

Among the advantages that may be mentioned in connection with the compounding of locomotives are :—

(1). Increased cylinder power in proportion to the capacity of the boiler.

(2). Economy in consumption of fuel.

(3). The whole of the available power of the expanding steam is used from its entrance to the H.P. cylinder at full pressure to its exit from the L.P. cylinder after being twice expanded.

(4). There is less loss due to condensation. In a simple engine there is a great range in temperament in the walls of the cylinder, because at every half-stroke of the piston steam is admitted at full pressure, and expanded down to atmospheric pressure. Now with the compound engine there is always steam pressure on both sides of the piston in the H.P. cylinder, thus keeping the walls of the cylinder at an even temperature, and the expansion in the L.P. cylinder is more gradual, and there is less variation in temperature.

(5). A more even distribution of the strains on the working parts, and larger bearings for the axles.

There are at present 40 4-cylinder compound engines at work on the L. & N.W. Railway, every one of which is double manned, is in steam 6 days of every week, and has a minimum of 316 miles cut out for its daily work. It may therefore be taken that while bearing the strain of running this enormous mileage day by day, a mileage which, to the best of my knowledge, is in excess of that expected from any other engine in existence, these compound engines are daily without assistance drawing loads of 300 tons, and running at an average speed of 52 miles an hour. The first one, "Diamond Jubilee," was turned out on 20th June, 1897, and the actual mileage run by this engine from when it was first put into traffic until the 31st December, 1900, was 221,510.

ENT TICE.

PLATE XI.

The L. & N.W. 8-wheel 3-cylinder compound engine of the "Greater Britain" class has two outside H.P. cylinders 15 inches in diameter, which exhaust into one L.P. cylinder 30 inches in diameter. This was the type immediately preceding the 4-cylinder compound engines now running on the same railway. From October 30th, 1891, when it was first put to work, until 31st December, 1900, "Greater Britain" ran 445,928 miles.

The "Jeanie Deans," a 6-wheel 3-cylinder compound engine, for many years worked the 2 p.m. corridor express from London to Crewe, returning with the up corridor train from Crewe, two of the heaviest trains in Great Britain. The actual mileage run by this engine from the time it was first put to work on 23rd December, 1890, until the 31st December, 1900, was 663,717, roughly speaking, 66,000 miles per annum. I may here give you a few interesting particulars of the mileage and consumption of the compound engines on the L. & N.W. Railway.

Statement showing the Miles run, quantity of Coal consumed, and consumption per Engine Mile by all of the Compound Engines since the date of first turning out to 31st December, 1900.

Number of Engines.	Class.	Total Miles Run.	Coal Consumed.	
			Cwts.	Lbs. Per Mile.
29	7′ Compound, 4-Cylinder.	2,897,916	1,077,217	42·8
10	7′ Compound, 8-Wheel.	3,434,689	1,184,897	39·8
10	7′ Compound, 6-Wheel.	6,180,648	2,084,456	38·0
10	6′ Compound, 8-Wheel.	1,243,518	498,319	46·1
40	6′ Compound, 6-Wheel.	21,277,250	7,444,175	40·4
30	6′ 6″ Compound, 6-Wheel.	16,798,587	5,041,740	34·8
110	4′ 3″ Compound, Coal.	8,259,379	4,048,591	56·1
	Grand Total and Average...	60,091,987	21,379,398	39·8

The figures for the consumption in the right-hand column include 1·2 for lighting up, standing waiting for trains, delays on the road, experimental runs, and all other purposes.

The 8-wheel 6-foot compound engines have been working on the heavy road to Carlisle, hence you will notice that their consumption is heavier than some of the others.

The 4-foot 3-inch compound coal engines are working the heavy coal, etc., trains to which I have already alluded.

(8). The Leading Varieties of Valve Gear.

The scientific and mathematical treatment of this important part of the machinery of a locomotive would form an inexhaustible topic, upon which I do not propose to enter at all, but the essentials of a good valve gear may be here stated.

It is necessary that when employed to work expansively it should admit steam freely to the cylinder during the period of the stroke when the admission is required, the ports being properly uncovered during the whole time of admission, to allow the free passage of the steam to the cylinders, and so prevent wire drawing or gradual reduction of pressure.

The cut-off should take place as quickly as possible, and the expansion should be as long as is consistent with satisfactory working. The release of steam from one side of the piston and the compression of the remainder in the cylinder on the other side should take place at such a point in the stroke as to avoid unnecessary back pressure, and yet provide sufficient resistance to balance the pressure of steam equally at both sides of the piston at the end of the stroke. By this means the momentum of the crank is allowed to overbalance the dead point at the end of the stroke.

The pre-admission should be just sufficient to allow the steam to gain its full pressure on the piston at the commencement of the stroke.

In 1843 the now famous link motion, illustrated in *Fig.* 27, was invented by a man named Howe, and applied by Messrs. Stephenson to the engines they were building. This valve gear solved the problem of working the steam expansively. In all other previous gears the engine could only be worked over at full throw, either travelling forwards or backwards. This, of course, meant that the engine was working at a great disadvantage, and under conditions that precluded the possibility of running at anything like a high speed. The simplicity of its construction and the favourable results that were obtained from Howe's gear at once brought about its almost universal adoption.

Many link and radial motions have since been produced, but Howe's is still the valve gear most extensively used in this country, although it has undergone considerable and continuous improvements in details of construction. The chief feature of this motion is the curved link, having as a radius the length of each eccentric rod.

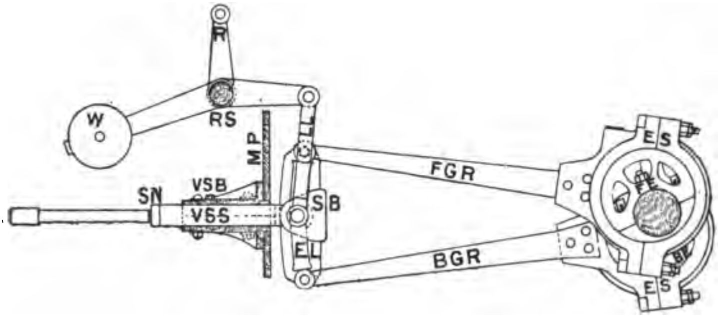


Fig. 27.

The gear is operated by a lever from the foot-plate. When in the forward position the top eccentric rod is brought in direct line with the valve spindle. When in back gear the bottom eccentric is brought in direct line with the valve spindle. When in mid-gear each eccentric revolves without operating the valve spindle. When it is desired to work the steam expansively, the curved link is gradually moved from the full gear position towards mid-gear, the period of cut-off depending on its proximity to the central position.

In 1865 Mr. Allen, Locomotive Superintendent of the Scotch Central Railway at Perth, invented the straight link motion, and *Fig.* 28 shows Allen's motion as applied to the express passenger and other locomotives on the London and N.W. Railway.

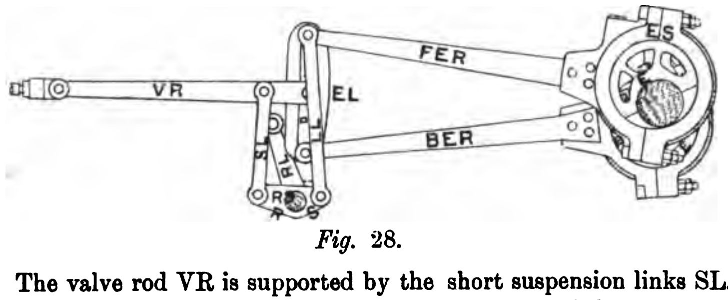


Fig. 28.

The valve rod VR is supported by the short suspension links SL, which are coupled at one end to the long lever R of the reversing

shaft. The short lever S is coupled to the long suspension or lifting links. These latter are attached at the other end to the forward eccentric rod FER, and to the top of the expansion link EL, the back gear eccentric rod BER being attached to the other end of the expansion link. EE are the eccentrics of cast iron, the eccentric rods being of Bessemer steel, fastened by screws and riveted to the cast-iron eccentric straps ES. D is the motion block or die block, which slides in the straight link, and is fixed to the end of the VR by means of a pin. RL is the reversing shaft arm (or lever), which is operated from the foot-plate by the reversing screw, or by any other suitable arrangement.

Mr. Webb has fitted the "Joy" valve gear to a number of North Western engines. The arrangement of this gear entirely dispenses with the four eccentrics and rods of the link motion, the necessary movement being obtained from the connecting rod.

The construction of locomotives to meet the demands of increased speed and power has necessitated the employment of larger cylinders, which, owing to the impossibility of altering the distance between the main frames, prevents the valve chest being placed between the cylinders. Now the "Joy" motion allows the valve chest to be placed either above or below them, and also admits of larger bearing surfaces being used for the driving axles.

Among the advantages claimed for this motion are:—

The number of working parts reduced.

The weight of the gearing reduced, and the fact that all the strains are central.

Its operation is said to be more correct and reliable, and gives the nearest approach to a theoretically correct distribution of steam in the cylinder.

Mr. Webb saw the benefits likely to be derived from this motion, and he was one of the first to practically apply it to locomotive engines. He first fitted it to a number of 6-wheel coupled goods engines with 18-inch cylinders with the most satisfactory results, and subsequently to the compound engines built at Crewe. *Fig.* 29 shows the "Joy" valve gear as applied to the low-pressure valve of a 3-cylinder compound engine. Q is the quadrant shaft of cast steel, carried by brackets fixed to the frames; the quadrant guides or facings FF are bolted to the shaft; working in the grooves of the quadrant guides are brass slide blocks SB, carried by the valve lever VL. At the point P the top joint of VL is attached to the connecting link CL at the point A. The

connecting link is coupled to the connecting rod of the engine CR at C, and at the other end to the anchor link AL, which is attached at the other end of the bracket B. This attachment is the only fixed point about the motion; the bracket is bolted to the guide plate of the leading radial axle-box. It is interesting to notice that while the point C of the connecting rod (to which the connecting link is attached) describes an oval, the point A of the latter describes a flattened ellipse, thereby imparting an equal motion to the point X. The motion is reversed by the lever R, which is fixed to one end of the quadrant shaft Q. The direction of the engine and the travel of the valve is regulated by the position in which the quadrant shaft is placed.

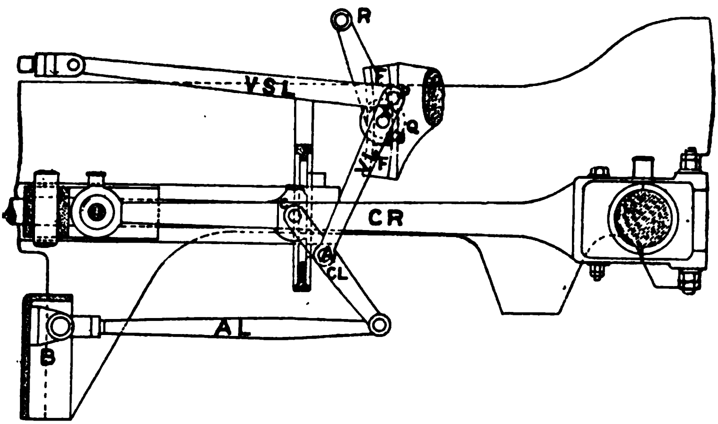


Fig. 29.

Several Locomotive Superintendents are using this valve gear with very good results.

With Mr. Webb's more recent type of 4-cylinder compound engines the valve gear used is "Joy's," which is applied to the low-pressure cylinders in the usual way. The low-pressure valve spindles are prolonged through the front of the valve chests, and each spindle is coupled up to a lever of the first order, which is carried on a pivot securely fixed to the frame, the other end of the lever being connected to the high-pressure valve spindle. Thus the high-pressure valves are worked from the low-pressure motion, through the intervention of the lever, which is so proportioned as to give the required travel to the high-pressure valve.

The lecturer here showed a very beautiful little model illustrating this arrangement, which had been kindly lent by Mr. Webb for the purpose of the lecture. The model clearly shows how the steam is exhaust from the high to the low-pressure cylinders, and also illustrates the piston valve, etc.

(9). The Use of Single or Coupled Driving Wheels.

The question of the relative uses of single and coupled driving wheels has already been alluded to, but I may here again briefly refer to it. It is generally admitted that single engines run with greater ease and freedom than when the wheels are coupled, and that all conditions being equal, they are probably superior in the matter of economy in respect of fuel consumption, also, having less wearing parts, they do not cost so much in shed repairs. There is also no doubt that when the weather and loads are favourable, single-wheeled engines possess greater possibilities in the matter of the attainment of high speeds.

I have known cases in which Mr. Ramsbottom's 7-foot 6-inch single engines have worked successfully, not only very fast trains, but also very heavy ones; but it is now, however, generally recognized that with modern express trains it is absolutely necessary to use two pairs of driving wheels if reliable timekeeping is to be maintained.

With single-wheel engines a good run one day may be followed by a fiasco the next. A slippery rail causes a great loss of time, and indeed single engines are not only often brought to a dead stand by slipping when working heavy trains up an incline, but when working trains of a very moderate weight.

The late Mr. Stirling made himself, and the Great Northern Railway, famous with the 8-foot single engines with outside cylinders 18″ × 28″ stroke, which made such splendid runs on the east coast route to Scotland; but Mr. Ivatt, his successor, realizes that single engines are not reliable for very heavy trains, and he is therefore building for the Great Northern Railway powerful engines with 6-foot 6-inch coupled driving wheels; this is a ten-wheeled engine with a large boiler and heating surface. It has cylinders 19″ × 24″, and is successfully working very heavy trains at high speeds.

For modern locomotive practice coupled engines with wheels from 6 feet 6 inches to 7 feet in diameter are the generally accepted type for working heavy express passenger trains. Mr. Webb's latest

express passenger compound engines have coupled wheels of the latter diameter.

The finest modern-built single-wheel engine is Mr. Johnson's, with 7-foot 9-inch driving wheels, a splendid specimen of which, "The Princess of Wales," was exhibited at the Paris Exhibition.

It has $19\frac{1}{2}'' \times 26''$ cylinders, 7-foot $9\frac{1}{2}$-inch driving wheels, and carries a pressure of 180 lbs. to the square inch. These engines are working trains of 150 to 200 tons at 52 miles an hour.

(10). Regulators.

Regulators are usually made of cast iron or brass, and are placed either in the dome or in the smoke-box adjoining the tube-plate. An early type of regulator, and one still commonly used, is shown in *Fig.* 30. It is an ordinary flat side valve working on a face with ports. The first movement of the regulator opens the small port, and the further opening of the regulator opens the large port, giving the full supply of steam to the cylinders.

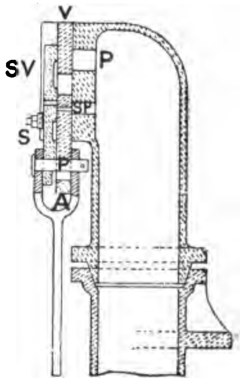


Fig. 30.

The "Ramsbottom" regulator, a modification of which is still in use on the L. & N.W. Railway, is shown in *Fig.* 31.

It consists of a double-seated valve V, fixed vertically in the dome on the end of the steam pipe SP. Attached to this valve is a rod R, which extends downwards and is connected to a small eccentric fixed on the end of a long rod, which extends horizontally through the barrel of the boiler, above the fire-box, and through the stuffing-box on the back plate of the fire-box shell to the regulator handle on the foot-plate.

At the end of this rod, working in a quadrant Q affixed to the boiler-plate, is a handle H, by means of which the driver moves the rod, thus causing the eccentric to revolve in the segment of a circle, and transmit the movement to the regulator valve, opening and shutting it to the extent to which the handle is moved.

When the boiler has no dome, another form of regulator is frequently used. It is placed in the smoke-box, and has two slide valves working horizontally, which are actuated by a rod passing from the regulator handle through the stuffing-box on the fire-box casing.

The majority of regulators are so constructed that the first movement of the handle opens a small port, the object being to prevent steam entering the cylinders too suddenly; when the piston heat is subjected to a sudden steam pressure, a great strain is placed on the engine, to avoid which steam should be applied very gently in starting an engine.

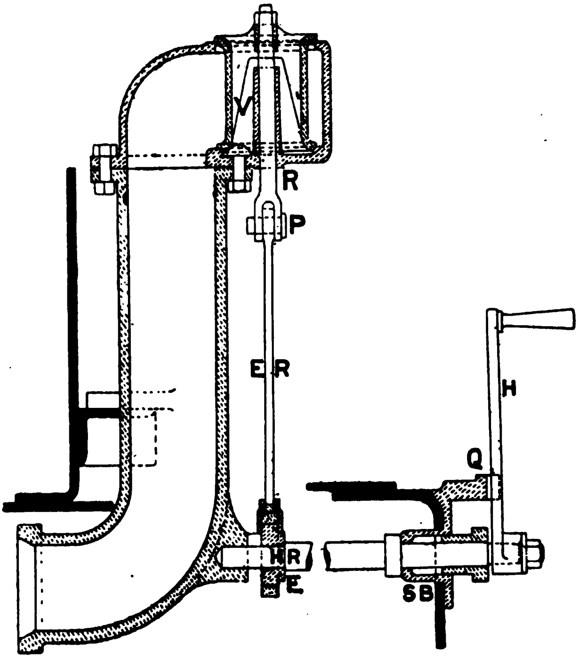


Fig. 31.

Mr. Webb has designed a regulator, which is placed in the smokebox. It takes the steam from the dome, but as the valve controlling the admission of the steam to the cylinders is so much closer to its work, there is less tendency to wire drawing, and a leak in the boiler steam pipe is no detriment.

(11). Blast Pipes.

The diameter of the orifice of the blast pipe is an important matter; the smaller it is the sharper the blast, and the more powerful its action upon the fire. A strong blast causes an engine to

steam well, but when the fire is too fiercely urged, a greater quantity of fuel is burned, besides which the contracted orifice for the outlet of the exhaust steam causes a back pressure in the cylinders, and prevents the engine from working freely. The point to be aimed at is to get the blast pipe as large as possible, consistent with the boiler making steam satisfactorily. There have been many experiments made from time to time in the construction of blast pipes, to determine their effect upon the working of an engine and the consumption of coal. It has been found that the influence exercised by the blast pipe upon the coal bill of a large railway company is very great, a variation of no more than an eighth of an inch in the size of the orifice producing most important results. An engine that has the heating surface and grate area properly proportioned to the size of the boiler and cylinders should, under ordinary circumstances, be capable of making steam with a blast pipe orifice not less than 5 inches in diameter.

The top of the blast pipe is usually about level with, or slightly above, the top row of tubes. It has often been thought that the vacuum in the smoke-box, caused by the blast, has a much stronger effect upon the upper than upon the lower rows of tubes, and therefore that the heating surface proper of the tubes is unequally distributed, the upper rows doing the greater part of the work. But whether from this cause or not, the upper rows do certainly wear away more quickly than the lower tubes, and more frequently fail from this cause.

To obviate this, and distribute the work evenly over the whole of the tube surface, the blast pipe is sometimes made shorter, and the barrel of the chimney extended downwards into the smoke-box, with a bell mouth above the top of the blast pipe. This arrangement has been applied to many L. & N.W. Railway engines with good results.

Mr. Adams, lately of the South Western Railway, brought out a blast pipe, for which he claimed that it acts equally upon all the tubes in the boiler. A transverse section of the smoke of a South Western Railway locomotive, fitted with the Adams vortex blast pipe, is shown (*Fig.* 32). It will be seen that the area at the orifice where the steam is discharged is between the two pipes BP and AP. The central pipe extends downwards, and diverges into a large bell mouth in front of the lower rows of tubes, through which the air is directly drawn. Thus the blast is made to act upon the lower rows of tubes. By this arrangement Mr. Adams claimed a great saving in the fuel consumed by the South Western engines.

Certain experiments to determine the amount of vacuum produced in the smoke-box prove that it averages 2·8 inches of water at the centre of the tube-plate to 15 inches at the base of the chimney.

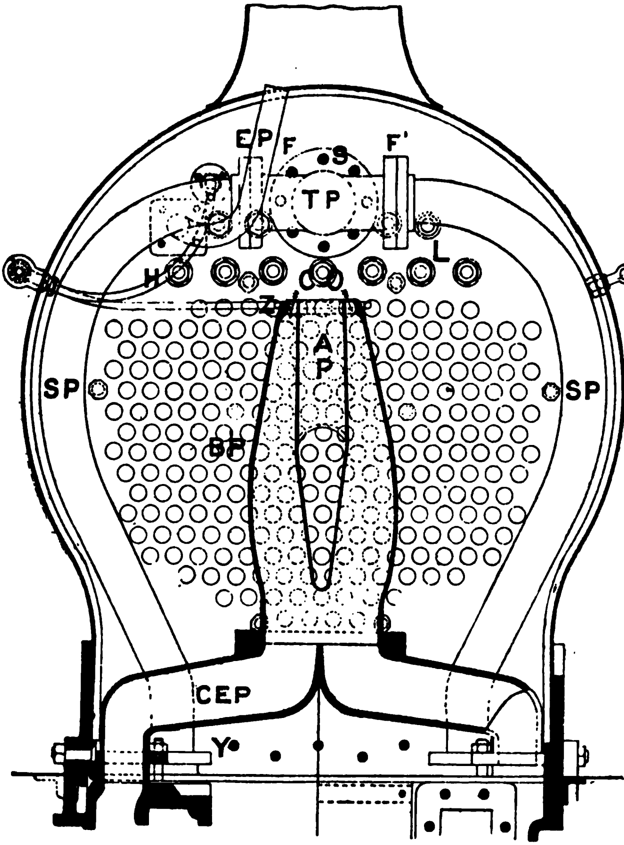


Fig. 32.

Closing the damper has the effect of raising the vacuum, and the greater the blast the greater the vacuum. What is needed is to regulate the damper in such a way that air is admitted below the bars in due proportion to the vacuum in the smoke-box.

Many experiments have been made with a view of improving the form of the blast-pipe. On the Continent, and on some English railways, adjustable blast-pipes are used, but most English engineers,

having arrived at a suitable size of blast-pipe for the working of the particular design of engine to which it is fitted, think it better to adopt the standard, because drivers, to save themselves trouble,. are apt to run with a smaller size pipe than necessary, thus causing a great waste of fuel.

An ordinary form of blast-pipe, as used by Mr. Drummond on the South Western Railway, is shown on *Fig.* 33.

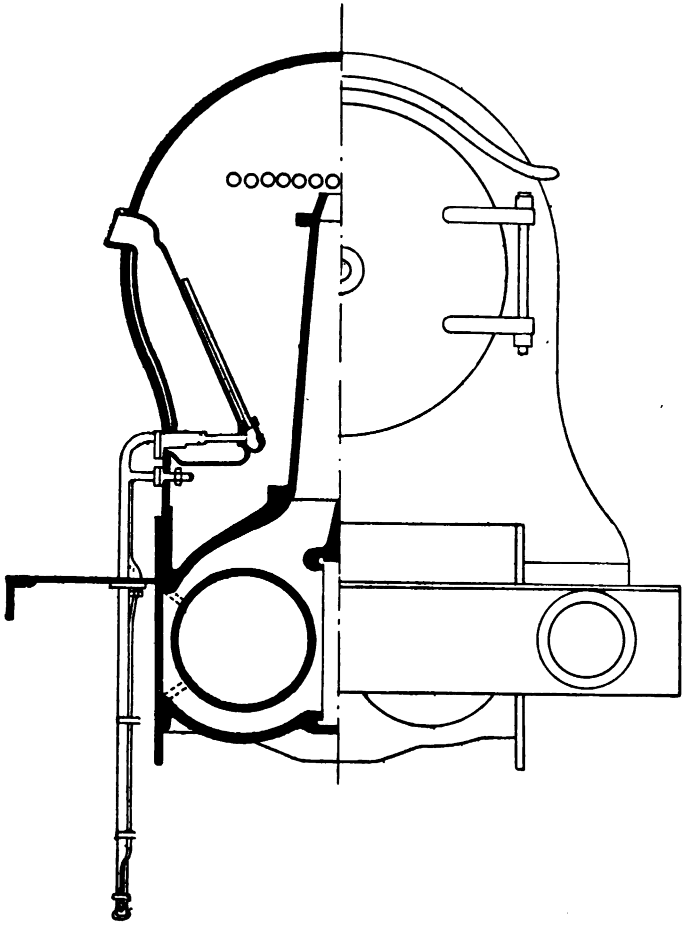


Fig. 33.

(12). Sanding and Steam Blast Arrangements.

The adhesion per ton of load on the driving wheels varies from 200 lbs. when the rails are slippery to 600 lbs. when they are dry. Every engine carries a supply of dry sand, stored in boxes, fitted with outlet valves worked from the foot-plate. When the rails are slippery the sand is allowed to run on them, and thus promote adhesion.

The sanding of rails is a most important function, indeed upon this the successful working of a single engine entirely depends if the rails happen to be in a slippery condition. I may go as far as to say that, had it not been for the great improvements in sanding gear lately brought out, single-wheel engines for working modern passenger trains would have been obsolete. The old-fashioned way of delivering sand on to the rails, perhaps two feet in front of the point of contact of the rail and tread of the wheel, means that the engine may slip very badly before the wheels get the benefit of the sand, if, indeed, they manage to get to the sanded rail at all.

By means of the steam blast sanding apparatus a combined jet of steam and sand is projected on to the rail at the point of contact between the wheels and the rails, and *Fig.* 34 shows Mr. Drummond's application of Gresham's patent sanding gear. You will notice that the sand-boxes are placed in the smoke-box, which is an excellent arrangement, and keeps the sand always dry and ready for use.

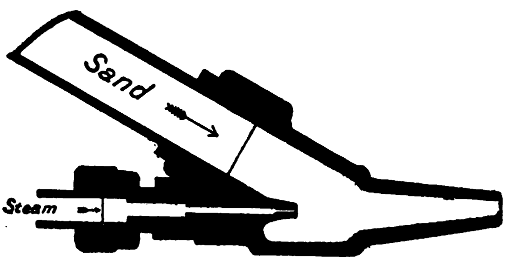


Fig. 34.

It is important that sand-boxes should be placed in such a position that they cannot get water in them. Failures have often been brought about by water congealing the sand, and preventing it from flowing freely.

(13). The Relative Merits of Steam and other Brake Gear.

There are three standard forms of brake fitted to locomotives in this country, viz., the steam brake, the vacuum brake, and the Westinghouse brake. According to the Board of Trade regulations, it is necessary that the brake on the engine should act automatically with the continuous brake on the train, and many of the railway companies using the vacuum or Westinghouse brake have that brake applicable to the wheels of the engine, so that the brake is uniformly applied on all the wheels either of the engine, tender, or train. This practice, no doubt, may have its merits, and those locomotive engineers, whose engines are fitted with the vacuum brake, inform me that it works well on the engine, and gives little trouble.

In cases where the Westinghouse brake is used I believe it is the universal practice to utilize the same brake on the engine as on the train. Of the two brakes, the one most favoured in this country is the automatic vacuum.

As you all know, the difference in principle between the two brakes is that the Westinghouse brake is worked by a pressure of from 75 to 80 lbs. per square inch, acting on a piston connected to the brake gear. With the vacuum brake the air is exhausted from the train-pipe reservoir and cylinder above and below the piston to the extent of 20 inches of vacuum, and the admission of air to the train pipe and lower part of the cylinder automatically cuts off the lower part of the cylinder from the reservoir and upper part of the cylinder upon which the piston is forced up by atmospheric pressure, and actuates the brake blocks.

On several of the leading railways the engines were fitted with steam brakes long before the introduction of continuous brakes. This was the case with the L. & N.W. Railway, Mr. Webb having fitted many of his engines with steam brakes several years before the introduction of the vacuum brake.

In order to comply with the requirements of the Board of Trade, the steam brake had to be made to work automatically with the vacuum brake. This is brought about by means of an ingenious arrangement, in which the valve actuating the steam brake is opened by a small piston, operated by steam from the boiler. This valve is closed by a piston of larger diameter, operated by atmospheric pressure due to the exhaustion of air from the train pipe. The atmospheric pressure acting on the larger valve diameter overcomes the pressure from the boiler, but when the brake is applied the

steam pushes out the small piston, and the brake valve is opened until the vacuum is again re-created. The steam brake is undoubtedly the most powerful, and on the whole it is perhaps the best brake that can be fitted to an engine.

The drawing (*Fig.* 35) illustrates Mr. Webb's steam brake, and its action can easily be seen. Steam is admitted to the cylinder below the piston, which it forces upwards, drawing up the arm of the lever which acts on the pull rod of the engine brake, and on the pull rod of the tender brake in the opposite direction, each set of blocks, so to speak, forming the fulcrum of the lever actuated by the pressure of steam.

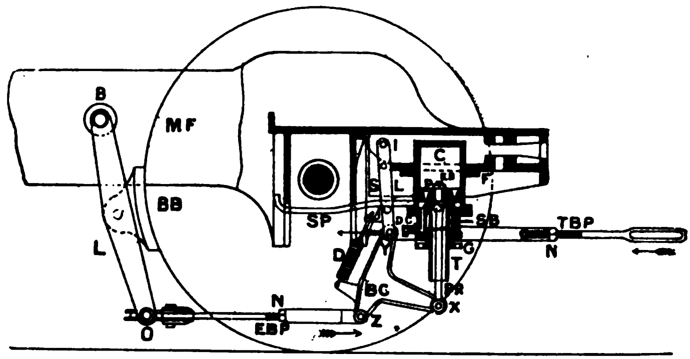


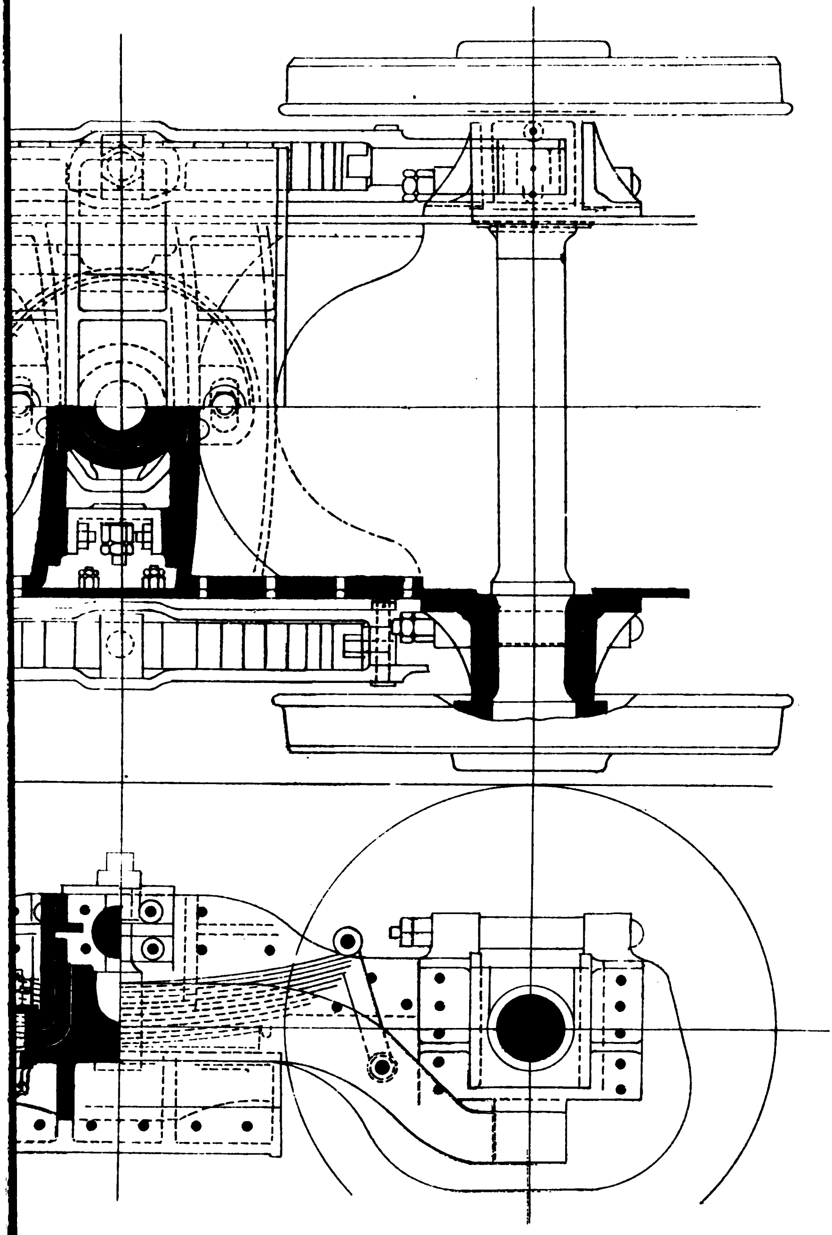
Fig. 35.

(14). Radial Bogies and Flangeless Coupled Wheels.

The radial bogie, or radial axle-box, has a very staunch advocate in Mr. Webb, who has always preferred its use for easing the rigid wheel base of his locomotives, instead of the more generally adopted form of bogie, and the Webb radial axle-box, illustrated in *Fig.* 36, has been successfully used on the L. & N.W. Railway. It possesses the great merit of economy and reduction of working parts, inasmuch as one pair of wheels is used instead of two.

Stretching between the main frames FF, and bolted to them in the manner shown, are the curved guides GG. These guides are rigid with the framework of the engine, and so is the spring frame SF, which is fixed to the centre of the guides. The radial axle-box AA is made of cast iron, and extends across, between, and through the frames, being curved to slide transversely in the guides. Bearings

L TRUCK.



of the ordinary description are fitted at either end of the radial axle-box.

Attached to the axle-box in the manner shown is the rod R, which passes through the spring frame, and is connected to the horizontal spiral springs HS, which are coiled right and left round the rod. When the engine enters a curve the springs are compressed towards one side, and take away any shock which may be transmitted through the wheels from the rails, allowing the box to slide laterally in the guides. When the engine gets on the straight road again, the springs resume their normal position, and keep the wheels central.

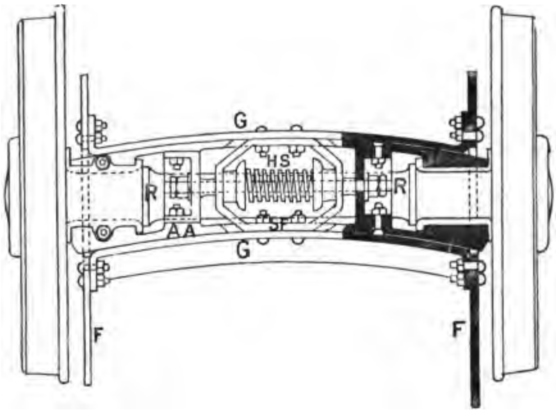


Fig. 36.

With the latest type of 4-cylinder compound engine one pair of wheels is not considered sufficient to carry the leading end, which is therefore mounted on a double radial truck. This truck has four wheels, but instead of being pivoted (as with the ordinary bogie), it is fitted with Mr. Webb's radial axle-box, with central side controlling spring, as shown in the illustration (*Plate* XII.).

Mr. T. W. Worsdell also designed a radial axle-box, which was used on the G.E. and N.E. Railways. This box had stays fitted to the guides, carrying an elliptical check spring of four plates, which acts in the same way as the spiral spring on Mr. Webb's box.

Radial axle-boxes are used on the L. & N.W., the G.E., the N.E., and the L. & S.W. Railways.

With engines that have six or eight wheels coupled, the rigidity

of the wheel base can be minimized, and the engine given greater freedom for travelling over curves, by having one pair of intermediate wheels without a flange. This is the case with the L. & N.W. 8-wheel compound coal engines, the pair of wheels immediately in front of the fire-box being so constructed.

(15). Leading and Trailing "Ponies" and the Adams "Bogie."

The "Bissel" or "pony truck" is much used in America for single axles. It consists of two ordinary axle-boxes sliding in guides attached to a short triangular frame, with its apex towards the centre of the engine, and secured by a pin on the centre line at a fixed point. A number of engines have been specially constructed by Mr. Webb for travelling round the sharp curves which abound on the brewery lines in and about Burton-on-Trent. These engines have the trailing end carried on a "pony," sketches of which are shown (*Figs.* 37 and 38).

The G.E. Railway had some engines of the American "Mogul" type fitted with "ponies."

The "Pony" or "Bissel" truck cannot, however, be said to have obtained any place in general English locomotive practice, and the ordinary form of bogie is most generally adopted to obviate a long wheel base. With goods engines that have six wheels coupled, the lateral play in the axle-box and horn-plates and the elasticity of the frames enable the engines to take ordinary curves with safety, but with passenger engines that have to travel at high speeds it is the general practice to have only two pairs of wheels rigid with the main frames, the leading end being carried on a bogie. Tank engines for local passenger services are usually fitted with bogies, sometimes at the leading and sometimes at the trailing end.

An example of the "Adams" bogie, which is a favourite type on English railways, is shown in *Fig.* 39. The bogie frames BF are made of steel, and are fitted with horn-plates in a similar manner to the main frames.

It must be clearly understood that the bogie is an entirely separate carriage, with its own independent wheel base, wheels, axles, axle-boxes, horn-plates, and all other fittings appertaining to a vehicle constructed to run on a line of rails. The only point at which the bogie comes in direct contact with the main construction

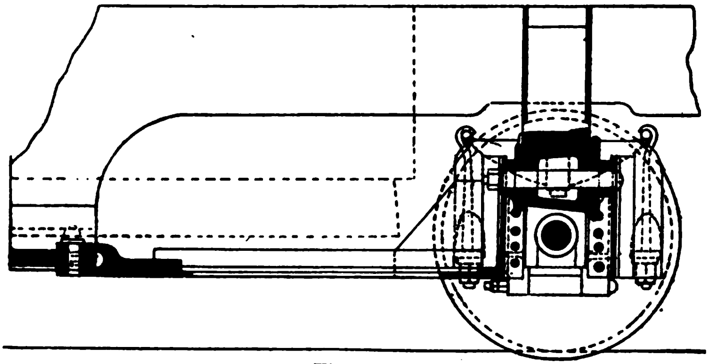


Fig. 37.

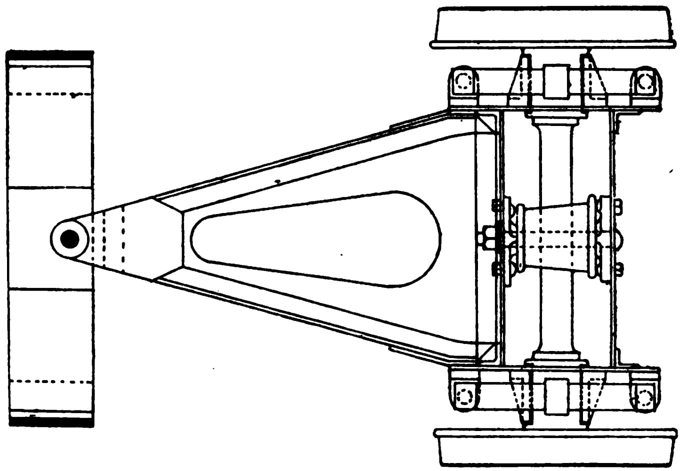


Fig. 38.

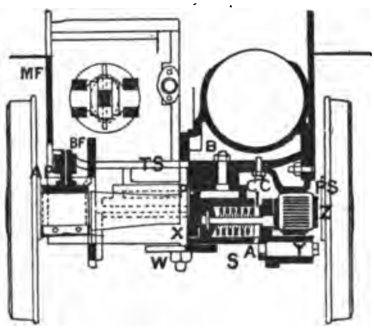


Fig. 39.

of the engine is where the pivot P fits into a hole in the centre casting CC, which rests upon the framework of the bogie carriage, and forms the floor or seating upon which the weight of the engine is carried. The shape of this casting will be understood upon referring to the illustration. It is not rigidly fixed to the bogie, but slides laterally in the guides G, which are fixed transversely between the bogie frames. The large bolt X passes through the pivot P and casting C, and at the end of the bolt is a large wrought-iron washer W, held in position by the nut beneath it; this bolt prevents the possibility of the engine and bogie becoming disconnected. The gun-metal ring GMR forms a bearing surface between the pivot P and the centre casting CC.

The bogie has two separate movements, viz., a circular motion round the pivot P and a lateral traverse between the guides G. The space I, which is $\frac{3}{4}$ inch, represents the distance allowed on either side between the centre casting and the bogie frame for the lateral traverse of the bogie in the guides G. The lateral or transverse movement is controlled by spiral springs at either side of the casting; one of these springs is shown in section at S at one side of the bogie. When the engine enters a curve the spring on the inner side is compressed, and when it passes from a curve on to a straight road the spring resumes its normal position, and the two springs keep the vehicle central. The weight is transmitted to the axle-boxes through the inverted plate spring PS, which is attached by the pin Y to the bogie frame at A. The ends of the springs rest in the stirrup-links LL, which are attached to the spring cradle Z, which transmits the weight to the top of the axle-boxes through the pillars AP, which can be screwed up and down to adjust the weight; the spring cradles Z are at either side of the bogie frames on the outside. Each cradle consists of two wrought-iron plates, between which the spring is fixed. These plates are brought together and welded at the ends, where they are attached to the adjusting pillars AP. The position of the spring PS in the cradle will be best seen in the cross-section at one side, and the attachment of the cradle to the axle-box at AP in the same figure on the other side, and at AP in the longitudinal section.

An advantage claimed for the Webb radial axle-box is that the natural tendency of the box and the spring is to resume its normal position. With a bogie, if one of the side springs is stronger than the other, it has a tendency to run the bogie sideways.

(16). Springs, Spring Hangers, and Equalizing Levers.

Of the springs generally used to act as a cushion between the dead weight of the engine and the journal of the axle-box upon which it runs there are three kinds, viz. :—

(1). Laminated steel plate springs.
(2). Spiral springs.
(3). Volute springs.

The most usual form of spring is composed of a number of curved steel plates fitting closely to each other, but not fastened together in any way except by the buckle in the centre; in fact, the ordinary locomotive spring is precisely the same as an ordinary carriage spring, except that it is much stronger.

The sketch (*Fig.* 40) shows a very simple form of spring attachment. The spring itself is composed of 19 steel plates, kept in position by the buckle; immediately under this buckle is the spring pillar, which works direct on the top of the axle-box through a guide bracket riveted to the frame. This pillar transmits the weight from the axle-box to the spring. The spring links or hooks are secured to the frame as shown, and the two ends of the spring fit into the hooks. In this form of attachment the spring and axle-box are self-contained, and are in no way connected with the weight upon any of the other axles.

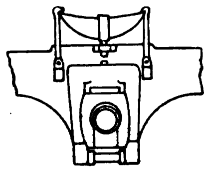


Fig. 40.

The springs must be adjusted with care, otherwise it may happen that some of the journals are carrying a great deal more weight than they should, while others are not carrying proper weight. It is sometimes the practice to use what is called equalizing levers. A North Western compound coal engine gives a very good example of a succession of equalizing levers automatically adjusting the weight between all the wheels on each side of the engine, and the diagram (*Fig.* 41) clearly shows the arrangement.

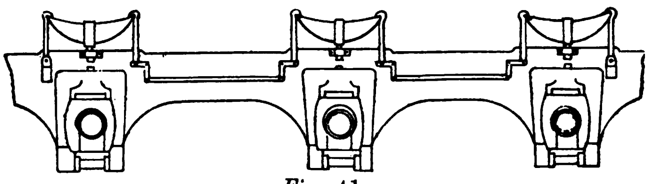


Fig. 41.

Fig. 42 shows the equalizing lever used between the two coupled wheels of a South Western express engine. In this case the springs are below the axle; the manner in which the carrying pin is coupled up to the top of the spring buckle, and in which the self-adjusting lever is coupled up to the ends of the springs, is clearly shown. With these equalizing levers it is necessary that the leverage should be exactly the samo at each end, otherwise the weight is not equally distributed. Springs must, of course, be of the very best steel, carefully tempered.

Fig. 43 shows the spiral springs carrying the weight of the trailing

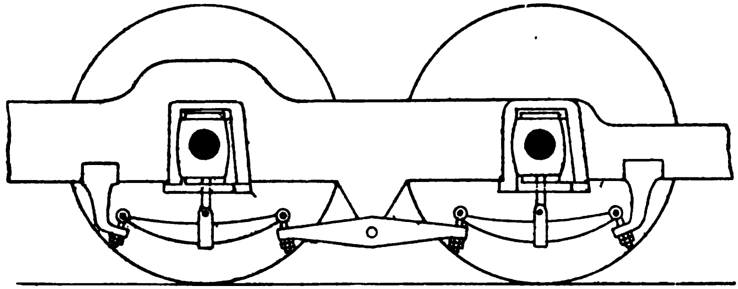


Fig. 42.

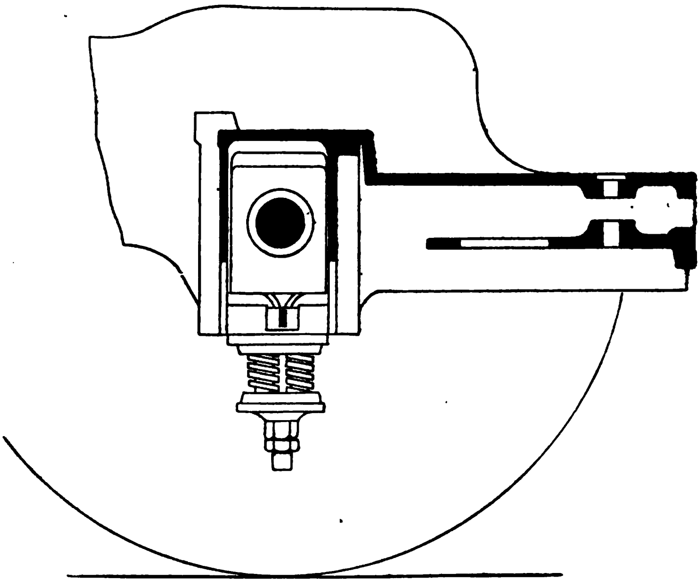


Fig. 43.

end of a L. & N.W. Railway 7-foot compound engine. There are four double springs, making a nest of eight springs connected by the hanger, or link, to the bottom of the axle-box. The weight is carried on the plate at the bottom of the spiral springs, and above the axle-box is the clearance for it to work up and down in the horn blocks.

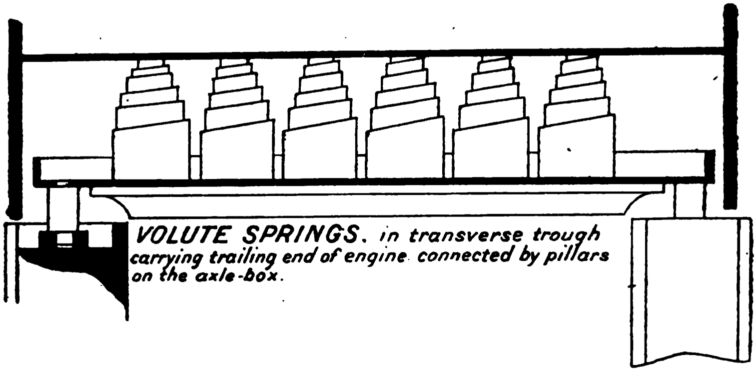


Fig. 44.

Fig. 44 shows the arrangement of Volute springs carrying the trailing end of a goods engine; the springs are placed in a transverse trough resting on the top of the trailing axle-box, and the engine is lowered on to them, the underpart of the foot-plate casting resting on the top of the springs.

(17). INCREASED BOILER CAPACITY DUE TO STEAM TRAIN HEATING.

I have already enlarged at some length upon the necessity of increased boiler capacity to meet the ever-increasing weight of modern trains.

This is the chief cause of the necessity for making larger boilers, and with steam-heated trains the steam used for this purpose does not in ordinary practice appreciably affect the working of the engine. An additional coach put on to a train of 15 vehicles puts a far greater tax on the boiler than the small amount of steam required for heating the train.

With L. & N.W. Railway steam-heated trains it is not necessary to keep the steam on continuously. Each compartment is provided with a "heater" containing acetate of soda. The driver every now

and then turns steam on from the engine, and the latent heat in the soda keeps the compartment warm.

The Midland trains are fitted with steam pipes running the whole length of the train on either side. The steam from the boiler passes down one side, and is led back by the other into the tank. The South Western also use a steam pipe, but the steam is taken from the exhaust, so there is no direct drain upon the boiler.

Far greater is the tax upon the boiler with a train fitted with electric light, where each vehicle has a dynamo driven off one of the axles. In this case additional power required for driving the dynamo is indirectly thrown on the locomotive, and practically acts as a brake on the train. An engine working from Crewe to London burns an additional 14 cwt. of coal if the train is fitted with the electric light.

(18). Tenders, Loads to be Carried, Tanks, and Pick-up Troughs.

Tenders in this country usually run on three pairs of wheels, from 3 feet 6 inches to 4 feet in diameter.

The framework of the tender consists of plates kept in position by cross-stays and the foot-plate at the leading end, which adjoins the foot-plate of the engine. The frames are fitted with horn-blocks, and the weight is carried by springs fixed in the same manner as shown in the illustration (*Fig.* 40) I have given of a North Western coal engine. Lately, in consequence of the increased weight of trains, and the long runs made without stopping, many companies have had to increase the size of their tenders, and tenders mounted on two bogies, with tanks carrying 4,000 gallons of water, have been introduced.

A good example of a tender running on two 4-wheel bogies is the one attached to Mr. McIntosh's express passenger engine running on the Caledonian Railway, and bogie tenders are now in use on various other lines.

Mr. Webb has remarked that he thinks the tendency of some engineers is to build their tenders as if they were very important pieces of machinery, spending a lot of money on them. He himself has always looked on them as water-carts, which should be built and hauled about as economically as possible.

The usual weight of a main-line tender in working order, with its maximum equipment of coal and water, is from 30 to 35 tons.

Mr. Ramsbottom's water pick-up apparatus introduced some 40 years ago renders North Western engines entirely independent of "water-stopping places," and enables this company to run with lighter tenders than other companies not using this system, as there is an appreciable diminution of the weight to be hauled.

The following table shows the different weights in working order of standard tenders on various railways, and it will be noticed that the North Western tenders are much the lightest:—

Railway.	Tank Capacity.	Amount of Coal carried for Weight given in Col. 3.			Weight in Working Order.		
	Gallons.	T.	C.	Q.	T.	C.	Q.
London, Brighton & South Coast ...	2,250	2	0	0	27	7	0
Midland	3,250	3	10	0	36	1	1
Caledonian	2,850		—		33	9	0
Great Northern	2,800		—		34	18	3
Great Eastern...	2,640	3	0	0	30	12	0
Manchester, Sheffield & Lincoln ...	3,080	4	0	0	35	0	0
North Eastern...	3,940	4	0	0	40	1	0
London, Chatham & Dover	2,600	4	15	0	34	3	0
London & South Western	3,000		—		32	0	0
Great Western	3,000	2	10	0	32	0	0
London & North Western .. .	1,800	4	0	0	25	0	0

An example of the "Ramsbottom" pick-up arrangement is shown in *Fig.* 45. The scoop is lowered by the engineman into the trough, and the speed of the train forces the water into the pipe P, from which it passes into the tank. When the tank is full, the scoop is placed in the "out-of-gear" position, where it is clear of the troughs.

Several other railway companies' engineers are now adopting the water pick-up arrangement. Mr. Ivatt, of the Great Northern, and Mr. Aspinall, of the L. & Y. Railway, are among those who have done so, and on their tenders the scoop is actuated by atmospheric pressure in connection with the vacuum brake.

The L. & N.W. troughs are usually about 500 yards long; they are 17 inches wide, and 6 inches deep. They are laid in the centre of the rails in the four-foot way; the depth of the water is about

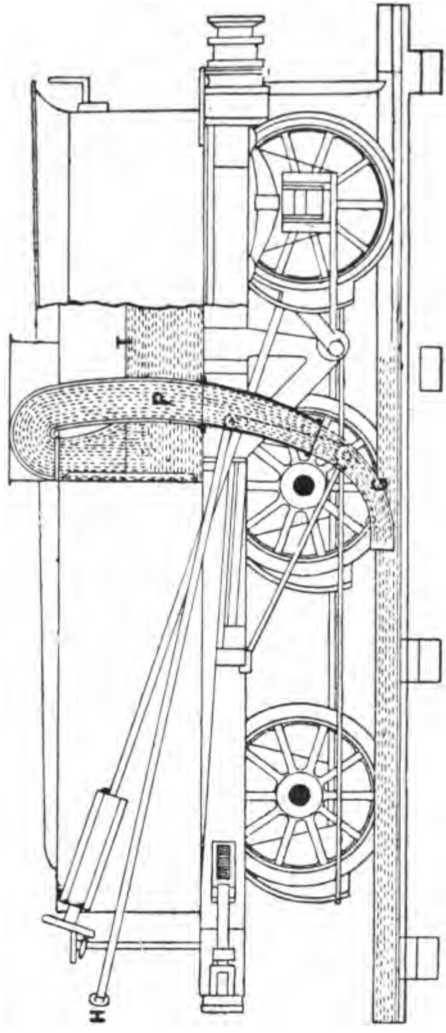


Fig. 45.

4 inches, and the supply is kept up by automatic valves, which refill the troughs when the normal depth is lowered. Seventy yards from each end of the trough the bottom slopes upward; the gradient of

the line 1 in 200 follows this slope, so that practically the bottom plate of the trough is at all times (whether in or out of water) in the same position with regard to the rail level.

(19). THE RELATIVE MERITS OF THE VARIOUS KINDS OF FUEL.

Wherever coal at a reasonable cost is obtainable, it is invariably the fuel of the locomotive, and the best kind for engines in this country is the anthracite, or blind coal, found in South Wales. It is expensive, but it contains at least 10 per cent. more carbon than any other kind of coal. It is the best for making steam, and perhaps not more expensive than cheaper coals in the long run when properly handled.

Coke has practically gone out of use altogether; in fact, a coke fire would not stand the fierce draught imposed on the modern locomotive.

With regard to liquid fuel, this has already been touched upon, but I may further remark that the liquid fuel that gives most satisfactory results is called "Astatki," which is a petroleum refuse obtained from Russia. Its S. gravity is ·8, and the flash point is 240°. The cost, however, of this oil in England is prohibitive, the price being 45s. per ton. The next best fuel is Borneo oil, a natural mineral petroleum with a flash point of 300°. This costs 40s. per ton in bulk in England.

The usual fuel used is gas tar oil, whose S. gravity is 1·1, and the flash point 300°. This oil is obtained from various gas works in different parts of the country, the cost ranging from 20s. to 25s. per ton. It is roughly estimated that the total inclusive cost of this fuel, including labour, etc., by the time it gets into the tender tank, is 30s. per ton. It is also estimated on some railways that the cost of coal when put on the tender is 20s. per ton.

It is stated that 1 ton of oil in actual practice is equivalent to about 2 tons of coal, therefore 1 ton of liquid fuel at 30s. is equal to 2 tons of coal costing 40s.

In some parts of Europe, particularly in Russia, different kinds of fuel are employed on the same line of railway. For instance, wood may be the best and cheapest fuel on one locality traversed, coal on another, and liquid fuel on another; and a passenger without changing his seat on a long journey may be hauled by engines using three different systems.

Shed Repairs.—There is, perhaps, a general impression among the uninitiated that a new or recently repaired locomotive, when turned out of the works, will run almost without attention until it is time for the engine to be again sent to the works for repairs.

This is quite erroneous. An express passenger engine ultimately intended to work trains running 150 miles or over without stopping, must first run several trips on local trains to enable the lubricator trimmings to be properly adjusted, and the wearing surfaces of the axles, valves, eccentrics, crank, coupling rod pins, and brasses to acquire that glassy smoothness which is only obtained by work, but which it is necessary to obtain before the engine can be said to be in perfect working order, and fit to run 200 miles without stopping, as is now frequently done, without a warm bearing or pin.

It is true that for the first few months after coming from the works an engine will require very little attention in the matter of repairs, provided the boiler is regularly washed, and no dirt allowed to accumulate in the water spaces.

But after two or three months hard running an engine begins to show signs of decreased efficiency, and it is necessary to overhaul the valves (especially in the case of piston valves), the pistons, and the slide blocks. It will often be found that piston and piston valve rings have lost their spring, thus allowing the steam to blow through, and with ordinary slide valves the faces may be wearing unevenly, in which case they must be taken out and faced up on the planing machine.

It will also be found that the pistons will require their rings changing, and that the slide blocks will require a liner inserting between the crosshead and blocks to take up the knock, or the blocks re-metalled. After three or four months' work, according to the quality of the water of the locality in which the running shed is situated, the boiler will begin to give trouble on account of leaking tubes, caused by the accumulation of scale in the barrel, preventing the proper circulation of water round the tubes, the ends of which become burnt off.

A number of tubes, sometimes as many as 30 or 40, will now require taking out to remove this scale, and at the same time the safety valve has to be taken off to clean the scale from the top of the fire-box. The rapidity with which scale will accumulate on the top of the fire-box is astonishing, and in some localities, if an engine were allowed to go six months without the top being cleaned, it would probably be found that the whole space between the top of the fire-box and the roofing stays was a mass of solid scale.

All accumulation of scale detracts from the steaming capabilities of the boiler, and it is also most important that the water spaces round the fire-box, as well as the top, should be kept perfectly free from dirt. Fast dirt in the water spaces causes damage to the fire-box through overheating of the copper plates and stay-bolts, causing the former to bulge and crack, and the heads of the latter to be burnt

off. Occasionally it is found necessary to remove stays for the purpose of removing dirt, although a good deal can be got down by hammering the stays after the steam and water have been blown out of the boiler, and the latter thoroughly dried.

The sketch (*Fig.* 46) shows what may happen if dirt in the water spaces is neglected. First, a cone of scale forms round the stay, then the copper plate wastes on the furnace side, because the water is not touching it on the other side. As the dirt accumulates the plates crack and bulge, and further neglect will result in the breakage of the stays; then the whole structure becomes dangerous. We had a very forcible object-lesson on the necessity of attention to fire-box plates and stays in the Government Inspector's report lately issued upon the recent boiler explosion on the Great Eastern Railway. It is a very interesting document, and I recommend its perusal to all those interested in the subject of locomotive maintenance.

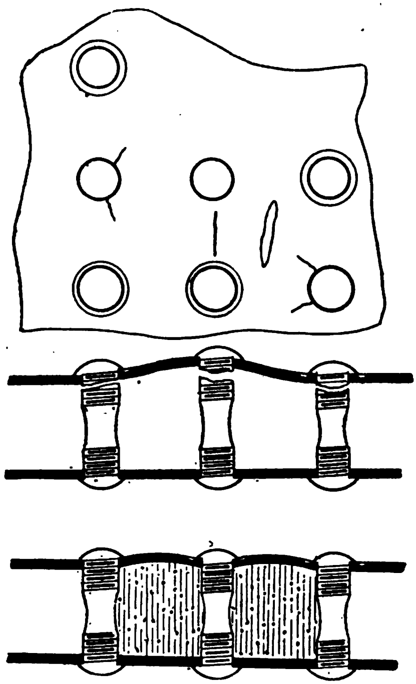


Fig. 46.

The shed boilersmith will, when a boiler-plate begins to crack in the stay-hole, drill and tap the plate through the crack, and after removing the stay insert a specially made rivet, which he draws

into position through one of the wash-out plug holes at the bottom of the fire-box by means of a piece of string. The rivet is then screwed off and the head riveted over, thus filling up the crack.

At sheds where the water is bad it is necessary to remove tubes for the purpose of cleaning the boiler about every four months, and the fusible plugs are changed every three months.

If an engine steams badly owing to leaking tubes, stays, or other defects, some drivers are in the habit of contracting the orifice of the blast-pipe, and sharpen the draught of the fire by using an instrument called a "jemmy." "Jemmies" are of various shapes, and the one which finds favour with drivers at the present time is shown in *Fig.* 47. The sharpened end is hooked over the top of the blast-pipe, and a wagon coupling hung on the bottom hook to prevent it being blown out by the exhaust.

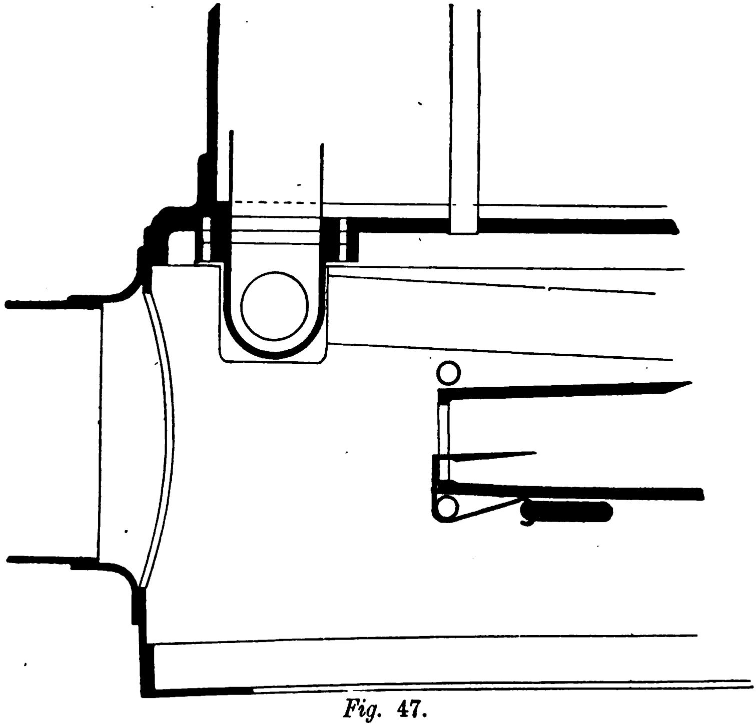


Fig. 47.

"Jemmies" are wrong, and should be suppressed when discovered. They cause back pressure in the cylinders, and the sharper blast is very detrimental to the boiler tubes.

A good driver should take steps to ascertain the cause of his engine steaming badly, and not resort to illicit means to get steam; but I fear that to a lazy fireman a "jemmy" is a friend, even when his engine is all right.

As regards the mileage an engine is capable of running between general works repairs, should no special defect occur, such as a cracked tube-plate or flawed axle, eighty thousand or even a hundred thousand miles is sometimes the figure attained, and some excellent mileage has been got out of the compound passenger engines stationed at Rugby.

As a general rule, however, it is found advisable to send an engine to the works when it has run seventy thousand to eighty thousand miles, because, although the engine may not be necessarily "run down," the wheel tyres will have worn hollow, and the flanges deep. This is a matter that requires careful watching; an engine working well, and giving little trouble, is liable to have this point overlooked. *Fig.* 48 shows the proper section of a tyre, and a tyre allowed to become so badly worn that the flanges do not clear the locking bars of the points. By the time the tyres are so worn as to require re-turning, the axle-boxes will require lining up where they fit in the horn-blocks. Their bearings will want re-fitting on the journals, and the tubes will require taking out.

The engine may then be said to require light general repairs, but when it is desirable to keep the engine out of the shops some time longer these repairs can be, and are, frequently done at the larger running sheds, where there is a wheel lathe, facilities for removing the wheels, and other machinery necessary for the execution of such work.

An engine requiring heavy boiler repairs should always be sent to the works.

I may now say a few words regarding the ordinary repairs done to engines between their trips. When a driver has hooked off his train, after completing his day's run, he brings his engine into the locomotive yard, and places it over a pit between the rails. Before leaving it is his duty to thoroughly examine every part of it, and assure himself that there is no undue play in any of the working parts, no nuts or pins missing, and that all the axles and other moving parts of the machinery have run perfectly cold.

He then proceeds to the shed and inserts details of the repairs required in a book provided for the purpose, leaving his engine to have the fire dropped, and be coaled for the next trip.

The fire is dropped by inserting a long hook through the fire-hole door, and lifting one end of the fire-bars out of the rack, the fire then

dropping into the ash-pan, whence it is raked out into the pit with a long rake.

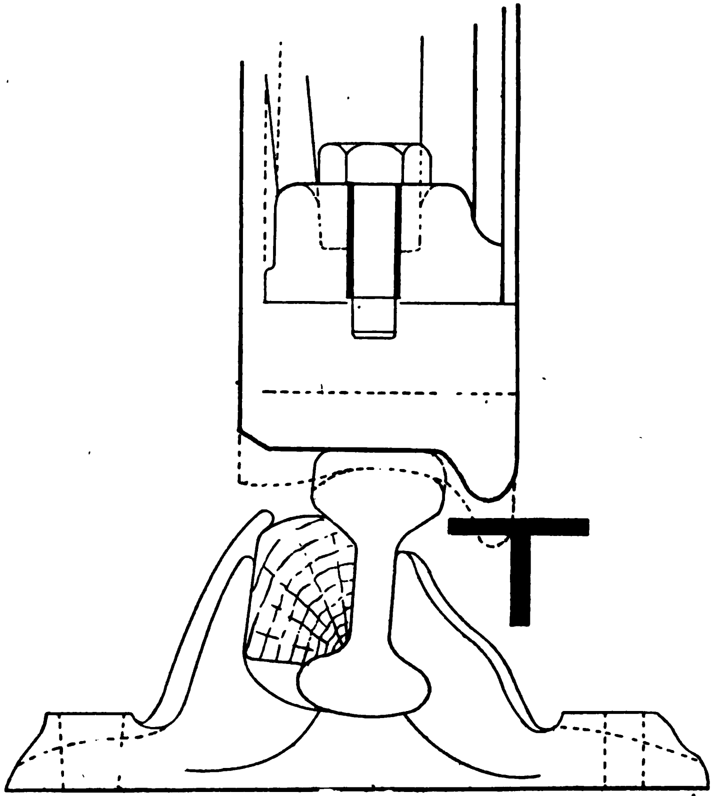


Fig. 48.

In warm weather, and especially when a very hot day succeeds a spell of cooler weather, an epidemic of hot axles usually breaks out, owing to the greater fluidity of the lubricant at the increased temperature, which causes it to run away through the syphons too quickly, and empty the oil boxes.

If an axle has been very hot, the wheels have to be taken out for the brasses to be refitted. In bad cases the white metal in the axle-box bearing will have been melted, and the journal of the axle cut. In bad cases of overheating, journals have been known to twist completely in two.

In order to remove the wheels the engine is brought into the shed, and run over a drop table, the construction of which may be seen in the diagram (*Fig.* 49).

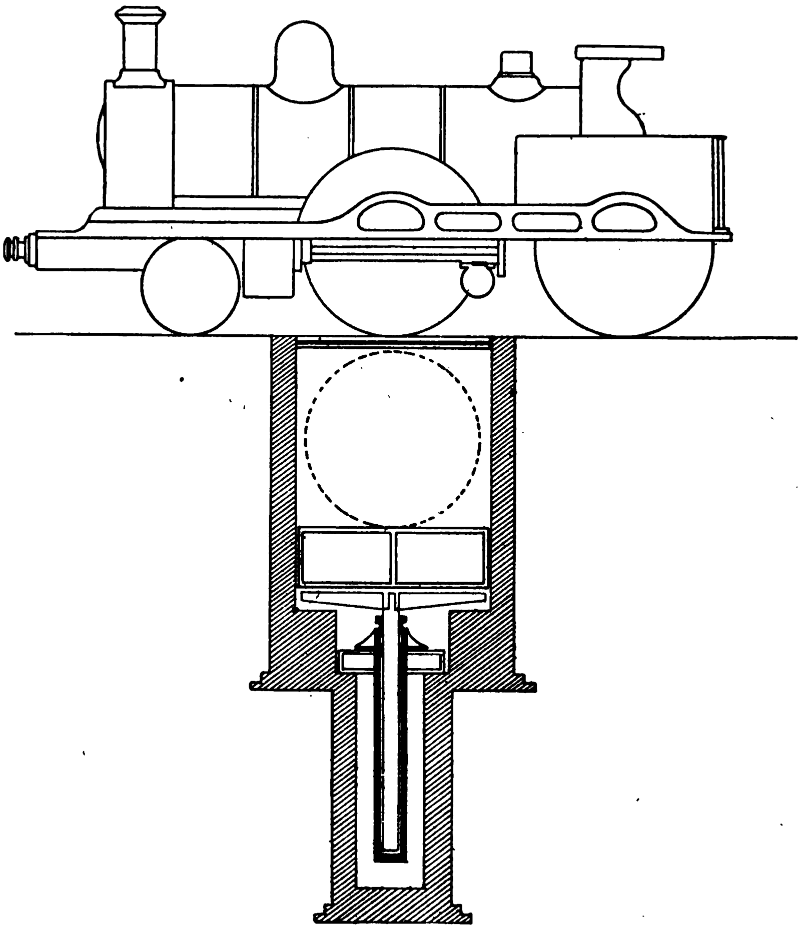


Fig. 49.

The engine is placed, with the pair of wheels which it is desired to remove, upon this table, which at the time is set and locked in its highest position. The horn-plate keeps, which secure the axle-boxes in the horn-plates, and all attachments having been removed,

the bolts securing the table are shot back, and the table lowered by the hydraulic cylinder, taking the wheels and axle-boxes with it.

On the table reaching the bottom of the pit another set of rails come automatically in position underneath the engine, which, resting on its remaining wheels, is taken clear of the pit. The wheels are then brought to the surface again, removed to a convenient place for the axle-boxes to be taken off to be re-metalled, and if the journals have not been cut by friction owing to the absence of lubricant, they are bedded down to the journals of the wheels, and placed under the engine again.

This operation frequently has to be performed between the regularly appointed trips of the engine. A drop lift is a very valuable adjunct to the plant of an engine shed, and this recently adopted practice of dropping the wheels out of the engine is far simpler and better than the old practice of lifting the whole engine off the wheels.

Among the other repairs done to engines in the running shed between their trips may be mentioned the renewal of piston rings, examination of injectors, and changing of broken springs.

Owing to the high piston speed of the locomotive and the great mileage now run, the piston rings require frequent renewal or they become thin, break up and get into the valve chest, where they are liable to do much damage, and finally to be thrown up the chimney by the exhaust.

The operation of renewing piston rings has been so simplified that two men can change a set of piston rings of a L. & N.W. goods engine or 4-wheel coupled passenger engine in about 1½ hours. They first place a special trolley running on the rails under the front buffer plank (see *Fig.* 50), and with the aid of adjusting screws on the same, make it take the weight of the plank. They then remove the bolts which fasten the plank to the engine framing, and the buffer plank, being free and resting on the trolley, is pushed out of the way, and the covers removed. The connecting rod is then disconnected from the cross-head from which the piston rod is drawn with the aid of a specially constructed hydraulic jack.

The piston heads and rods can then be removed, the old rings removed, new ones substituted, and the engine coupled up again.

Broken springs are also a prevalent locomotive malady. It is important that all the springs of an engine should be of approximately equal strength, in order that the weight on the different axles may be properly distributed. The weights on the axles of engines not

fitted with compensating arrangements can be altered by means of adjusting screws, which increase or decrease the camber of the springs. When an engine is fitted with a new spring it is run upon the tables of a special weighing machine, which registers the weight on each wheel, and the weights are adjusted while the engine stands on the table.

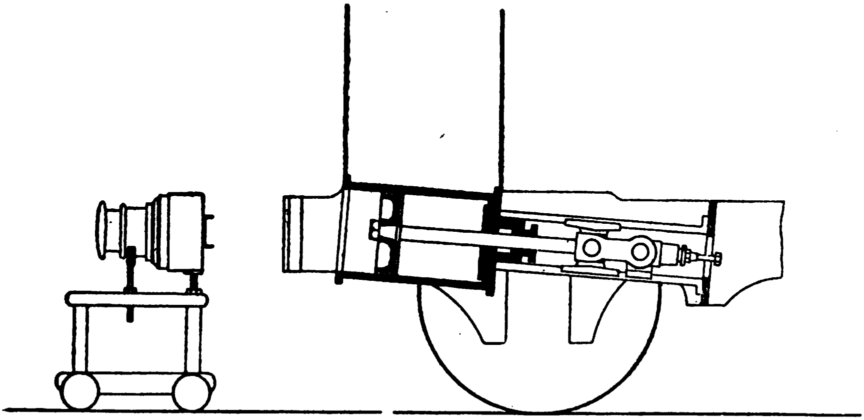


Fig. 50.

Amongst other shed work may be mentioned the making of cylinder and valve cover joints, safety valves, and dome cover joints.

Cylinder cover joints often develop a blow owing to the carelessness of the drivers in allowing water to accumulate in the cylinders when the engine is standing. In the case of the back covers blowing, the re-making of the joint is a job of considerable magnitude, involving the taking down of the slide bars, cross-head, piston, etc.

Grinding in equilibrium regulator valves, injector steam valves, closing of eccentric straps, big end connecting rod brasses, and making whistle stand joints, a job which necessitates removal of cab, etc., steam-pipe joints in boilers and smoke-boxes, and other jobs too numerous to mention, form other items of shed repairs.

Besides being examined by the driver after his daily trip, all engines are periodically examined in the shed by an examiner, who looks out for such special defects as cracks in axles, coupling rods, and motion links, defective springs, etc., which a driver would probably not notice. Cracks in the eccentric rods and smaller parts of an engine can usually be put right if discovered before they

have become far developed by heating the rod at the crack, and inserting a wedge, but if this is not done at once the crack is liable to extend ; in the same way a crack may develop in a sheet of glass or lamp globe.

Coupling rods frequently develop flaws on their under side, usually about their middle, owing to the whip of the rod when the engine is running at high speed. Flaws sometimes develop in forged steel crank axles, the cracks appearing usually at the points shown in the sketch (*Fig.* 51), and they are liable to extend until they become a source of danger.

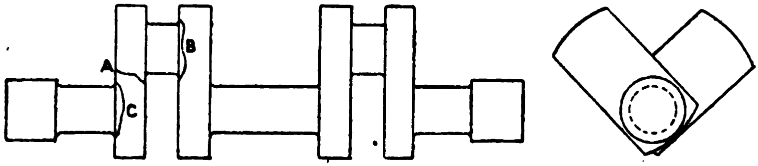


Fig. 51.

Mr. Ivatt, in 1891, read a very interesting paper on this question, in which he proved that this development may not be brought about by actual strain in ordinary working, but by vibration. If the crack could be seen directly it commenced, and cut right out, the axle, although weakened in sectional area, would last much longer than if the crack had been allowed to go on. Believing that the vibration alone would cause a crack in a steel axle to extend as rapidly as it would under ordinary working, he had an axle of the kind shown in *Fig.* 51 slung up, and subjected to blows at the end from a weight swinging to and fro on a pendulum at the rate of 3·6 blows per minute.

These blows were continuous, and were worked off a cam attached to a stationary engine.

The original crack, in consequence of the discovery of which the axle was taken out of the engine, was at the point A. The crack at B began to show about three or four months after the experiment commenced, and after the axle had received some 645,000 blows. The crack at C was discovered later some two months before the axle finally dropped off at the crack B, so that although there had been a bad flaw at A, the axle did not finally break, but developed flaws at B and C when doing no work at all, but when subjected to the vibration described.

When a crack in the web is discovered, and has not gone too far, the axle may be made fit to work by shrinking on iron hoops, as shown in *Fig.* 52.

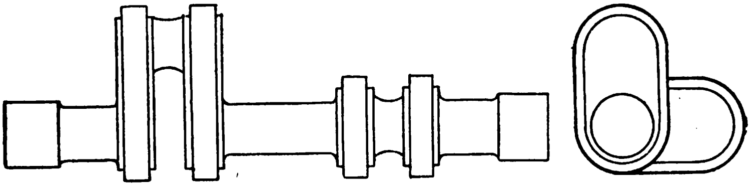


Fig. 52.

On the L. & N.W. Railway built-up cranks are largely in use. These are cheaper to manufacture than forged cranks, and are not so liable to develop flaws.

I might say much on the work of the engine driver, his duties and responsibilities, but I have already tried your patience too far. These responsibilities have vastly augmented since the time when the early trains on the Liverpool and Manchester Railway weighed about 75 tons, and jogged along at the comfortable speed of 15 miles an hour. How different are the conditions existing to-day, when, with all the complex machinery of the modern locomotive to look after, he has to work trains weighing three to four hundred tons mile after mile at 60 miles an hour, and has in all weathers, by day or by night, to pick out his own particular signals from the gigantic array that face him as he approaches the many complicated junctions and busy depôts which abound on our English railways.

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